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ECTOMYCORRHIZA – NATURE AND SIGNIFICANCE FOR FUNCTIONING OF FOREST ECOSYSTEMS

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Abstract

The ectomycorrhiza has a great influence on vegetation and for the forest ecosystems it is essential. The present review aims to provide brief information about main participants – myco- and phytobionts in such a well-organized mutualistic association, their structural elements, function and role in the natural processes. It also emphasizes that ectomycorrhizas has no equal value through the fungal species. Furthermore the last complement each other in their ecological niches and as a result we can observe optimal exploration of site which is very outlined in habitats, where there is a deficit on one or more mineral elements. Describing ectomycorrhizal mycocoenosis is very challenging task and provide valuable information about all the community as a whole. For this, the molecular markers are excellent tools but must be combined with morphological and anatomical studies, because only thorough studies can bring better understanding of the driving processes at ecosystem levels.

Key words: common mycelial network, extraradical mycelium, Hartig net, mantle, mycorhizosphere.

Introduction

Mycorrhiza (pl. mycorrhizas, mycorrhizae) (fungus root) is a symbiotic relationship that is not pathogenic or is slightly pathogenic, resulting in a fungus root association between plant and fungus (Kirk et al. 2008). The term mycorrhiza was derived from the Greek ’μυκόσ‘ – fungus ’ριζα‘ – root and was used for first time by Frank in 1885 in his work ’On the nutritional dependence of certain trees on root symbiosis with belowground fungi‘ to describe two different organisms forming a single morphological structure – fungus root (Frank 2005). There is a high accuracy in this first attempt on morphological description of mycorrhiza.

Mycorrhizas differ significantly through various groups of plants, in the way of interaction between fungus and plant, respectively within the fungal species involved in this association and the type of obtaining nutrients. Therefore, they are classified in different types (Harley 1991, Agerer 1995, Smith and Read 2008). One of these types of mycorrhizas, most often studied and of great importance for the boreal regions, is the ectomycorrhiza.

According to Molina et al. (1992) there are six features characterizing the ecological phenomenon of mycorrhiza. These

are: 1) dependence–independence – determines whether the plant is involved in mycorrhizal symbiosis or not, under natural conditions; 2) facultative and obligatory symbiotrophic relationship – determines the ability and inability of symbiotrophs to complete the whole cycle of development in the absence or not of mycorrhiza or mycorrhizas; 3) mycorrhizal type – determined by the fact that most of symbiotrophs form a certain type of mycorrhiza, but some of them (the mycobionts and photobionts – together or separately) can participate in the formation of two or more types of mycorrhizas and this depends on abiotic and biotic conditions, and the ontogenetic stages of development; 4) photobiotic range – it is determined by the scope that go from narrow (usually family) to medium, and finally wide, which include plants that spread beyond the family, including a few close or more distant ones, as well as a separate order or above order; 5) mycobiontic compatibility – determines the number of mycorrhizal fungi that are associated with certain photobiont and according to Molina et al. (1992) there are two groups: plants, associated with low number and plants associated with high number of fungi; 6) ecological specificity – it is determined by the influence of abiotic and biotic factors on the ability of plants to form functional mycorrhiza with fungi under certain conditions of the natural environment.

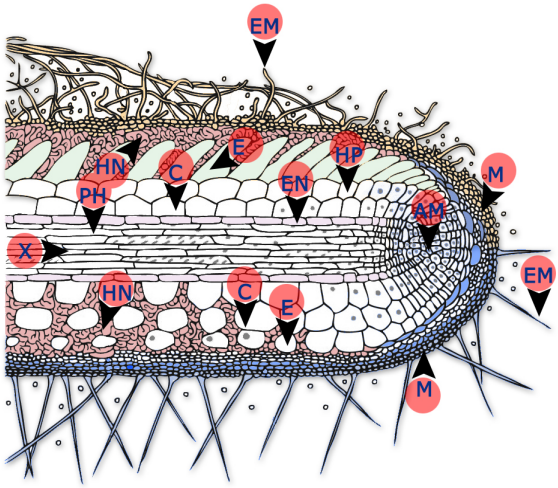

Fig. 1. The main features of ectomycorrhiza – view in longitudinal section in gymnosperms (lower half) and angiosperms (upper half).

Note: M – mantle (blue and yellow), HN – Hartig net, EM – extraradical mycelium, E – epidermal cells, HP – hypodermis, C – cortex cells, EN – endodermis, PH – phloem in the main cylinder, X – xylem in the main cylinder, AM – apical meristem.

Structural Features of Ectomycorrhiza

The ectomycorrhizal associations are called ectotrophic associations or ectomycorrhizas. They are a mutualistic relationship between fungi and vascular plants. From a morpho-anatomical point of view, ectomycorrhiza forms a functionally separate unit, acting alone, represented by fungus hyphae and root cells located outside the endodermis (Fig. 1). The main differentiating features from other types of mycorrhiza is the presence of three structural elements: 1) a veil or mantle that covers the root surface; 2) Hartig net – a labyrinth-like structure, built by branching hyphae and situ-

ated between dermatogen and periblem, and 3) extraradical mycelium and its formations, representing a system of hyphal components, located outside the mantle and making the connection to the sporophores of ectomycorrhizal fungi.

The structural features of the mantle and extraradical mycelium are constant at least at genus level and can serve as important characters for recognition of the fungal partner (Agerer 1986–2008, Ingleby et al. 1990, Goodman et al. 1998, Agerer and Rambold 2004–2011). The ectomycorrhiza is easily distinguishable from other types of mycorrhiza on the basis of clearly noticeable absence of penetration of the hyphae into the intracellular space. If it occurs, the type of the mycorrhiza is classified as ectendomycorrhiza (Peterson et al. 2004). In some cases, one fungus is capable to form ectomycorrhiza with some plants and in other – ectendomycorrhiza. This also depends on the peculiarities of abiotic factors. For instance, *Wilcoxina mikolae* Chin S. Yang & Korf forms ectomycorrhiza with young plants of genera *Pinus* L. and *Larix* Mill. In the nurseries under natural conditions it forms an ectendomycorrhiza with species of the genera *Abies* Mill., *Picea* A. Dietr. and *Tsuga* Carr. (Mikola 1988). The species of genus *Wilcoxina* have very high ecological importance because they participate in the mycorrhizal association with species of genus *Pinus* under the extreme conditions and are probably crucial for the ecological plasticity and occurrence of trees (Fig. 2).

For example, the stalk base of the pine tree shown in Fig. 2 is under water surface near half a year and the dam is frozen for at least another three months (Fig. 2.1). A great excess of water and nutrients makes the fine roots grow mainly in the upper parts of soil. For a very limited time, among the third and fourth quarter of the year the water level goes down, and temperatures in the ground surface rise dramatically (Fig. 2.2). Through this time there is a high risk of starting of decaying processes and ectomycorrhiza develops rapidly, protecting the finest roots. In this Scots pine tree, two morphotypes are observed: ≈ 5 % probably *Lactarius* sp. (Fig. 2.3) and the most abundant ≈ 95 % *Wilcoxina* sp. (Fig. 2.4).The last one (39AJ45) was DNA sequenced in Germany. The comparison with the known fungal databases showed only the genus *Wilcoxina* (99 % match – DQ320129 – Uncultured Wilcoxina isolate NS30C1 18S ribosomal RNA gene, partial sequence; internal transcribed spacer 1, 5.8S ribosomal RNA gene, and internal transcribed spacer 2, complete sequence; and 28S ribosomal RNA gene, partial sequence. – CLC Genomics Workbench) (see Fig. 3).

Abbreviation of codes: WM – *Wilcoxina mikolae* (Chin S. Yang & H.E. Wilcox) Chin S. Yang & Korf; WR – *Wilcoxina rehmii* Chin S. Yang & Korf; WA – *Wilcoxina alaskana* Kempton, Chin S. Yang & Korf; WS – *Wilcoxina* sp., uncultured.

The closest related known species to isolate 39AJ45, according to the phylogram is *Wilcoxina alaskana*. It forms small, 6–12 mm in diameter apothecia with ochraceous hymenium (Yang and Korf 1985).

Most ectomycorrhizal fungi in extreme conditions are able to penetrate intracellularly through the older parts of the root system or where the nutrient balance in the ectomycorrhizal association is disturbed (Smith and Read 2008). In this case, the fungus appears to be a little pathogenic. The latter can probably be observed in the individual stages of development of the plant and some combina-

Fig. 2. Ectomycorrhizal morphotypes associated with *Pinus sylvestris*, 1935 m above sea level, in extreme conditions, Belmeken dam.

Fig. 3. Phylogenetic relationships in genus *Wilcoxina*, according to the available information in the NCBI GenBank (1995–2014).

tion of influencing factors, i.e. the impact and the benefits to the partners do not always show a symmetry. Contrariwise, there are dynamic fluctuations over the

time. In most cases, a weak pathogenic effect occurs on the plant and less on the fungal partner. Many of the typical ectomycorrhizal fungi involved in symbiotic relationships with species from genera *Pinus* and *Fagus* L. are forming mycorrhiza with the ericoid species and in this case it is defined as arbutoid (Harley 1985) due to different anatomic structure of root and its influence to hyphae growth.

The three attributes for ectomycorrhiza are not constant, and there are lesser or greater variations in the manner in which the mantle is developed, Hartig net or extraradical mycelium in different plant species also vary. In some species of Asteraceae (Warcup 1980) only a part of the mantle is present and in species of the genus *Pinus*, forming the mycorrhiza with *Tricholoma matsutake* (S. Ito & S. Imai) Singer, the mantle is not observed (Yamada et al. 2006). The roots of *Pisonia grandis* R.Br. do not form a Hartig net (Ashford and Allaway 1982). All these mycorrhizal types functionally belong to ectomycorrhiza.

Plant Species Involved in Ectomycorrhiza (Photobionts)

Plant species involved in ectomycorrhiza are a relatively small number (not more than 5 % of vascular plants), but their representatives are very important because among them are nearly all woody plants that determine the vegetation appearance in large geographical areas (Meyer 1973). These include species of Pinaceae, the main components of the vast northern boreal areas and Fagaceae – dominants and subdominants in the northern (*Fagus* L.*, Quercus* L.) and southern (*Nohtofagus* Blume) temperate zones. In Australia the ectomycorrhizal species are all in the genus *Eucalyptus* L'Hér. (Peterson et al. 2004).

The most spread mycorrhiza is vesicular arbuscular mycorrhiza (VAM) and it occurs mainly in the herbaceous plants. Their general characters are vesicles (not always) and arbuscules – special mycelial morphological structures, who penetrates into the cellular space. Fungal partners in this type mycorrhiza are those from order Glomerales.

Some classes of plants are forming both VAM and ectomycorrhiza. For instance, the species, combining both type of mycorrhizas are these belonging to family Myrtaceae (incl. *Eucalyptus*) and also the widespread in temperate geographic zone genus *Salix* L.

Almost all species involved in ectomycorrhizas are trees but there are exceptions – some families composed of typical shrubs, and a very limited number of herbaceous plants (Table 1). However, most of genera are not studied in depth yet and we can expect more numbers, forming ectomycorrhiza.

Table 1. Genera of plants, with at least a species involved in ectomycorrhiza.

Family/Subfamily	Genus
Angiospermae	
Aceraceae	B *Acer* L.
Betulaceae	B *Alnus* Mill.
	B *Betula* L.
	B *Carpinus* L.
	B *Corylus* L.
	B *Ostrya* Scop.
	B *Ostryopsis* Decne.
Bignoniaceae	*Jacaranda* Juss.
Caprifoliaceae	B *Sambucus* L.
Casuarinaceae	B *Casuarina* L.
	B *Allocasuarina* L.A.S.Johnson
Cistaceae	B *Helianthemum* Mill.
	B *Cistus* L.
Compositae (Asteraceae)	B *Lactuca** L. (incl. *Mycelis* Cass.)
Cyperaceae	B *Kobresia** Willd.

Dipterocarpaceae	B *Anisoptera* Korth.
	B *Balanocarpus* Bedd.
	B *Cotylelobium* Pierre
	B *Dipterocarpus* C.F.Gaertn.
	B *Dryobalanops* C.F.Gaertn.
	B *Hopea* Roxb.
	B *Monotes* A.DC.
	B *Shorea* Roxb. ex C.F.Gaertn.
Elaeagnaceae	*Shepherdia* Nutt.
Epacridaceae	*Astroloma* R.Br.
Ericaceae	*Arbutus* L.
	Arctostaphylos Adans.
	Chimaphila Pursh
	Gaultheria Kalm ex L.
	Kalmia L.
	Leucothoe D.Don
	Rhododendron L.
	Vaccinium L.
Euphorbiaceae	*Poranthera* Rudge
	B *Uapaca* Baill.
Fagaceae	B *Castanea* Mill.
	B *Castanopsis* (D. Don) Spach
	B *Fagus* L.
	B *Lithocarpus* Blume
	B *Nothofagus* Blume
	B *Pasania* Blume
	B *Quercus* L.
	B *Trigonobalanus* Forman
Gentianaceae	*Bartonia** Muhl. ex Willd.
Goodenaceae	*Brunonia** Sm. ex R. Br.
	B *Goodenia** Sm.
Hammamelidaceae	*Parrotia* (DC.) C. A. Mey.
Juglandaceae	B *Carya* Nutt.
	B *Juglans* L.
	Pterocarya Nutt. ex Moq.
Fabaceae – subfam. Caesalpinoideae	*Afzelia* Sm.
	Aldina Endl.
	Anthonota P. Beauv.
	Bauhinia L.
	Brachystegia Benth.
	Cassia L.
	Eperua Aubl.
	Gastrolobium R. Br.
	Gilbertiodendron J. Léonard
	Julbernardia Pellegr.
	Monopetalanthus Harms
	Paramacrolobium J. Léonard
	Swartzia Schreb.
	Acacia Mill.
Fabaceae – subfam. Mimosoideae	*Chorizema* Sm.
	Daviesia Sm.
Fabaceae – subfam. Papilionoideae	*Dillwynia* Sm.
	Eutaxia R. Br.
	B *Gompholobium* Sm.
	B *Hardenbergia* Benth.
	Jacksonia R.Br. ex Sm.
	Kennedya DC.
	B *Mirbelia* Sm.
	B *Oxylobium* Andrews
	Platylobium Sm.
	Pultenaea Sm.
	B *Robinia* L.
	B *Vicia* L.
	B *Viminaria* Sm.
	Comptonia (L.) J. M.Coulter
	Myrica L.
Myricaceae	B *Angophora* Cav.
	B *Callistemon* R.Br.
	B *Campomanesia* Ruiz & Pav.
Myrtaceae	B *Eucalyptus* L'Hér.
	B *Leptospermum* J.R. Forster & G. Forster
	B *Melaleuca* L.
	B *Tristania* R.Br.
Nyctaginaceae	B *Neea* Ruiz & Pav.
	B *Torrubia* Vell.
	B *Pisonia* L.
Oleaceae	B *Fraxinus* L.
Platanaceae	B *Platanus* L.
Polygalaceae	*Coccoloba* P. Browne
Polygonaceae	*Polygonum** L.
Rhamnaceae	*Cryptandra* Sm.
	Pomaderris Labill.
	Rhamnus L.
	Spyridium Fenzl
	Trymalium Fenzl
Rosaceae	B *Crataegus* Tourn. ex L.
	B *Dryas* L.
	B *Malus* Mill.
	B *Prunus* L.

	B *Pyrus* L.
	B *Rosa* L.
	B *Sorbus* L.
Salicaceae	B *Populus* L.
	B *Salix* L.
Sapindaceae	*Allophylus* L.
	Nephelium L.
Sapotaceae	*Glycoxylon* Ducke
Sterculiaceae	B *Lasiopetalum* Sm.
	Thomasia J.Gay
Stylidiaceae	B *Stylidium* Sw.
Thymeleaceae	B *Pimelea* Banks & Sol. ex Gaertn.
Tiliaceae	B *Tilia* L.
Ulmaceae	B *Ulmus* L.
	Celtis L.
Vitaceae	B *Vitis* L.
Gymnospermae	
Cupresseceae	B *Cupressus* L.
	B *Juniperus* L.
Pinaceae	*Abies* Mill.
	Cathaya Chun & Kuang
	B *Cedrus* Trew
	Keteleeria Carrière
	Larix Mill.
	Picea A. Dietr.
	Pinus L.
	Pseudolarix Gordon
	Pseudotsuga Carrière
	Tsuga Carrière
Gnetaceae	*Gnetum* L.

Note: * – herbaceous plants; B – representatives of the genera forming simultaneously ectomycorrhiza and VAM (modified from Smith and Read 2008).

Origin of Ectomycorrhizal fungi

The most ancient evidence for ectomycorrhiza was found in British Columbia (Canada) in fossil roots of *Pinus* species, and dates more than 50 million years ago (LePage et al. 1997). It is believed, however, that ectomycorrhizal relationships have more ancient origins and appeared roughly about 130 ± 1 million years ago (Smith and Read 2008).

Phylogenetic studies (Hibbett et al. 2000) have shown that it is very possible the formation of ectomycorrhiza derives independently from several clades of fungi and has evolved into a long period of time from different fungal organisms – saprotrophs forming subsequently symbiotic relationship with autotrophic plants. Since the dynamics of the process is different in various latitudes, structurally there is a wide range of ectomycorrhizal variety. The question, however, is still discussible about the reversibility of the process of changing the trophic level. It is believed that for only one species of genus *Lentaria* Corner (Bruns and Steffarson 2004) there is enough evidence to argue that the fungus has moved from ectomycorrhizal to saprotrophic life style and this can be considered more as an exception than as a rule. It is possible, however, for other fungi to have covered the same evolutional paths.

Compared to VAM, ectomycorrhiza is younger with approximately 250 million years. The oldest fossils of mycorrhizal sample found up to date appear to be those of VAM and were dated 400 million years ago (Remy et al. 1994).

Fungi Involved in Ectomycorrhizal Associations (Mycobionts)

According to Molina et al. (1992), the fungi forming ectomycorrhiza are between 5000 and 5500. However, the current number is estimated between 20 000 and 25 000 species, bearing in mind that the known fungi represent not more than 20 % of all existing, and even 5–10 % according to some authors (Deacon 2006). Various comparisons between the floristic richness

studied in detail and the fungal diversity on a particular territory revealed the regularity, which indicates that they are 5 to 6 times more than the tracheophytes species. About 80 % of ectomycorrhizal fungi have epigeous spore-forming structures, and in others, they are formed below the surface and are called hypogeous. Both types are characterized by a great variety of morphological and ecological features. The latter are hard to locate. The overall assessment of the global species richness of ectomycorrhizal fungi varies considerably according to different authors, and there is a trend of increasing their number in the most recent studies. Many families were considered as ectomycorrhizal, but in many studies there is no clear evidence of their current trophic status. For instance, up to date, there is no proof for the ectotrophic status of *Morchella* Dill. ex Pers. species. Their cultivation trials failed in most cases. Its saprotrophic status is either well understood and leads to the conclusion that some species can form a very complex life style, which follows their specific ontogenetic pathway.

Rinaldi et al. (2008) analyzed the trophic status of the most fungal genera by reviewing a large amount of publications and the conclusion was that of over 300 fungal genera known to be ectomycorrhizal, the published data till now is incomplete or the status is unconfirmed and completely hypothetical for about one third of them. As an evidence of the latter, they analyzed the scientific proofs, dividing them into: morpho-anatomical characteristics of naturally occurring ectomycorrhizal fungi; synthesis of pure cultures, molecular, isotopic analysis and phylogenetic studies. Due to the limitations of each method, the authors proposed to clarify the trophic status for the combinations of them, and the more methods are available, the evidences of the ectomycorrhizal status of the species are more obvious and indisputable. According to the estimation, based on various publications, total number of ectomycorrhizal fungi (modified) is about 8334, which significantly exceeds the number proposed by Molina et al. (1992). However, here it should be noted that authors use different methodologies to assess, and different views of taxonomists exist, who often raise a taxon within a species based on certain criterion, mainly morphological, often not clear enough and not well-established. The modern molecular methods are an excellent tool to solve the existing uncertainties and taxonomic problems.

It can be assumed that the current knowledge on the diversity of ectomycorrhizal fungi supported by experimental evidence is only partially complete and that the inclusion of many fungal families in the trophic and ecological category should be done only after thorough studies, supported by appropriate scientific evidence.

The fungi involved in ectomycorrhiza are associated with a particular plant taxon, most often family or families and usually the occurrence of sporophores are indicators of the habitat in similar conditions. Different studies have shown that the most common spatial distribution of ectomycorrhizal communities is a patchy type (Peter 2000).

The formation of spore-forming structures does not always, however, give a clear picture of species composition and population size because it often varies and depends on the combinations of different factors. It happens frequently, that the species forming these structures often inhabit a relatively small proportion of physiologically active root system, while

others, which do not form or does it rarely, occupy a large part of it. All this leads to the conclusion that in most cases there is little or no obvious correlation between the aboveground and belowground spatial distribution of ectomycorrhizal communities. Several studies confirmed this, and revealed also that a significant part of ectomycorrhizal fungi can form sporophores rarely and sporadically. The results from the long-term observation plots performed by Egli (2009) for a sporocarps inventory showed clearly two tendencies – only very small number of mycorrhizal fungi produce sporophores regularly, i.e. to discover the most fungal diversity we need a long term observations, and a trend of decline in ectomycorrhizal fungal diversity.

It has been found that the number of different fungi, associated with a particular host plant is much fewer than the fungal species, forming ectomycorrhiza with the same plant. It is possible for the individual plant (photobiont) to participate in ectomycorrhiza with 20 or more species at the same time. Modern molecular methods, particularly DNA analysis, have proven the last fact using microsatellites (Saari et al. 2005). It is more likely to be a result of different evolutionary pathways for development on one hand, and of a different strategy for the propagation and life cycle, on the other. The most important factors for occupying the ecological niches by ectomycorrhizal fungi in their natural habitats are tree age, soil, climatic conditions and availability of ectomycorrhizal inoculum.

Due to the relative ecologically equal value of most ectomycorrhizal fungi, they compete each other. As a result, the species occupy different ecological niches and complement themselves. For instance, it is not unusual to observe several species on the same rootlet, neighboring each other. The main reasons are: different growing optimum parameters (temperature/humidity) of each ectomycorrhizal fungus; the surrounding micro- and mesofauna, flora and mycota at the impact on the formation and distribution of specific microenvironment. The last is mainly composed of different bacteria and endophytes and some of them play a positive role and form a complex relationship with the plant and/or the ectomycorrhizal fungus or fungi. This is true especially for the dark septate endophytes, which are located in the root system and have a neutral to slightly positive effect, and for some types of bacteria (Jumpponen and Trappe 1998). Most endophytes, located in the root are septate fungi with dark color, from phylum Ascomycota but some of them are colorless (O'Dell et al. 1993). For example, very often on/in the roots of woody plants are found species of *Mortierella* Coem., an ecologically important group which are the first organisms colonizing roots. Salt (1977) reported, that they occur much more often on the root surface of genus *Picea* species, compared to species of the genera *Fusarium* Link, *Pythium* Pringsh, which are pathogens. The role of *Mortierella* species for the plants is not enough understood, but two things are known presently – they did not impact negatively on the trees' health status, and even more – occupying the roots, they blocked the access of some nutrient resources used by the pathogens. Some of *Mortierella* species grow rapidly on FDA and MN[1] medium and make the isolation of axenic culture of ectomycor-

[1]FDA (Ferry medium) and MN (Melin-Norkans medium) – modified or original recipes are one of the most common media for isolation of ectomycorrhizal fungi.

rhizal fungi from ectomycorrhizal rootlets difficult and even impossible.

The fungus *Suillus tomentosus* (Kauffman) Singer produces specialized structures with *Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm, known as tuberculate ectomycorrhiza. The possible reasons are probably within the mechanism of protection from insects and pathogens in addition to becoming a host of nitrogen fixing bacteria, which allows the plant to grow in/on poor in organic nitrogen soils (Paul et al. 2007). This is an example of mutualistic association wherein among plant and fungal species are involved other organisms – bacteria.

One of the most active directions in the study of an ectomycorrhizal symbiosis is the relationship between fungal diversity and establishment of mycocoenological association. There is an increasing support for the hypothesis that ectomycorrhizal fungal species diversity affects the structure of plant communities, which in turn influences them. It is formed by complex combinations of abiotic and biotic factors. One of the most important biotic factors in this respect is the photobiont specificity or selectivity (Zhou and Hyde 2001). The latter phenomenon may be considered from 'phytocentric' or 'mycocentric' terms, i.e., to emphasize the influence of fungal symbiotrophs that combine with particular plant taxon or a variety of plant species.

Studies of the ectomycorrhizal diversity and selectivity of particular plants can be made only when the basic information on the trophic status of fungi in an ecosystem is known. Such knowledge is also necessary to study the habitats in wider aspects where fungi play an important role in biochemical cycles. It is important to know which of them are ectomycorrhizal and which have saprotrophic or mixotrophic (dual) life style (Taylor and Alexander 2005, Koide et al. 2005).

Fungi involved in ectomycorrhiza belong to three major groups. These are from the phyla: Basidiomycota, Ascomycota, and family Endogonaceae (Table 2). The species of last group have an aseptate coenocytic mycelium, unlike the first two fungal groups which belong to the higher fungi, many of which are macromycetes.

Despite the functional similarity of ectomycorrhiza, the number of fungi involved in it is quite large and unevenly represented among the three groups above. The species from phylum Basidiomycota are the most numerous among them. Table 2 presents the majority of fungal families forming ectomycorrhiza.

The total number of ectomycorrhizal species is about 8328. In Europe to date 1518 macroscopically ectomycorrhizal fungi from phylum Basidiomycota are established (Moser 1983, Jülich 1984).

Modern molecular methods open new opportunities in the investigation and determining of fungi trophic status in which data interpretation plays a key role. For first time in 2006, the entire genome of epigeous fungus *Laccaria bicolor* (Maire) P.D.Orton was completely read (Martin et al. 2007). This fungus was chosen among many other ectomycorrhizal fungi because it is widespread and has a large phytobiontic spectrum. Its genome is 65 Mbp and is much larger than of other fungi from Basidiomycota, which have been completely sequenced. The results show that more than 50 % of genes are with unknown function. Over 20,000 proteins are found and have been identified. Among them, the most important are protease, lipase, phytase and about 315 others involved in carbohydrate metabolism,

Table 2. Fungal genera, forming ectomycorrhiza (by Rinaldi et al. 2008 – modified).

Fungal genera	Number of known species
Ascomycota Caval.-Sm.	
Amylascus Trappe	2
Balsamia Vittad.	6
Barssia Gilkey	2
Cazia Trappe	1
Cenococcum Moug. & Fr.	1
Chloridium Link	1
Choiromyces Vittad.	5
Delastria Tul. & C. Tul.	1
Dingleya Trappe	7
Elaphomyces Nees	20
Eremiomyces Trappe & Kagan-Zur	1
Fischerula Mattir	2
Genea Vittad.	35
Geopora Harkn.	12
Geopyxis (Pers.) Sacc.	6
Gilkeya M.E. Sm., Trappe & Rizzo	1
Glischroderma Fuckel	1
Gymnohydnotrya B.C. Zhang & Minter	3
Gyromitra Fr.	15
Helvella L.	40
Humaria Fuckel	15
Hydnobolites Tul. & C. Tul.	2
Hydnocystis Tul. & C. Tul.	2
Hydnotrya Berk. & Broome	12
Hydnotryopsis Gilkey	2
Kalaharituber Trappe & Kagan-Zur	1
Labyrinthomyces Boedijn	7
Leptodontidium de Hoog	1
Loculotuber Trappe, Parladé & I.F. Alvarez	1
Meliniomyces Hambl. & Sigler	3
Muciturbo P.H.B. Talbot	3
Mycoclelandia Trappe & G.W. Beaton	2
Neocudoniella S. Imai	2
Nothojafnea Rifai	2
Otidea (Pers.) Bonord.	15
Pachyphloeus Tul. & C. Tul.	6
Paradoxa Mattir.	1
Paurocotylis Berk.	1
Peziza Dill. ex Fr.	84
Phaeangium Pat.	1
Phialocephala W.B. Kendr.	6
Phialophora Medlar	1
Picoa Vittad.	4
Plicaria Fuckel	1
Pseudaleuria Lusk	1
Pseudotulostoma O.K. Mill. & T.W. Henkel	1
Pulvinula Boud.	24
Reddellomyces Trappe, Castellano & Malajczuk	4
Ruhlandiella Henn.	1
Sarcosphaera Auersw.	1
Sowerbyella Nannf.	14
Sphaerosoma Klotzsch	3
Sphaerosporella (Svrček) Svrček & Kubička	2
Sphaerozone Zobel	4
Stephensia Tul. & C. Tul.	6
Tarzetta (Cooke) Lambotte	8
Terfezia (Tul. & C. Tul.) Tul. & C. Tul.	12

Tirmania Chatin	3
Tricharina Eckblad	12
Trichophaea Boud.	20
Tuber P. Micheli ex F.H. Wigg.	63
Underwoodia Peck	1
Wilcoxina Chin S. Yang & Korf	3
Wynnella Boud.	1
Basidiomycota R.T. Moore	
Afroboletus Pegler & T.W.K. Young	5
Albatrellus Gray	12
Alnicola Kühner	~30
Alpova C.W. Dodge	20
Amanita Pers.	~500
Amarrendia Bougher & T. Lebel	1
Amaurodon J. Schröt.	6
Amogaster Castellano	1
Amphinema P. Karst.	4
Anamika K.A. Thomas, Peintner, M.M. Moser & Manim.	3
Andebbia Trappe, Castellano & Amar.	1
Arcangeliella Cavara	12
Aroramyces Castellano & Verbeken	2
Astraeus Morgan	2
Aureoboletus Pouzar	5
Auritella Matheny & Bougher	7
Austroboletus (Corner) Wolfe	30
Austrogaster Singer	3
Austrogautieria E.L. Stewart & Trappe	6
Austropaxillus Bresinsky & Jarosch	9
Bankera Coker & Beers	2
Boletellus Murrill	50
Boletochaete Singer	3
Boletopsis Henn.	5
Boletus Dill. ex Gray	300
Bothia Halling, T.J. Baroni & Manfr.	1
Boughera Vernes, Johnson & Castellano	1
Byssocorticium Bondartsev & Singer	9
Byssoporia M.J. Larsen & Zak	1
Calostoma Desv.	15
Cantharellus Adans. ex Fr.	65
Castoreum Cooke & Massee	2
Chalciporus Bataille	15
Chamonixia Rolland	8
Chlorogaster Læssøe & Jalink	1
Chondrogaster Maire	1
Chroogomphus (Singer) O.K. Mill.	15
Clavariadelphus Donk	18
Clavulina J. Schröt.	32
Coltricia Gray	13
Coltriciella Murrill	7
Corditubera Henn.	5
Cortinarius (Pers.) Gray	~2000
Craterocolla Bref.	2
Craterellus Pers.	20
Cribbea A.H. Sm. & D.A. Reid	4
Cystangium Singer & A.H. Sm.	7
Cystogomphus Singer	1
Dermocybe (Fr.) Wünsche	15
Descolea Singer	10
Descomyces Bougher & Castellano	3
Destuntzia Fogel & Trappe	5
Diplocystis Berk. & M.A. Curtis	1

Efibulobasidium K. Wells	2
Entoloma (Fr. ex Rabenh.) P. Kumm.	~100
Fevansia Trappe & Castellano	1
Fistulinella Henn.	15
Gallacea Lloyd	5
Gastroboletus Lohwag	10
Gastroleccinum Thiers	1
Gastrotylopilus T.H. Li & Watling	1
Gautieria Vittad.	25
Gigasperma E. Horak	2
Gomphidius Fr.	10h
Gomphogaster O.K. Mill.	1
Gomphus Pers.	10
Gummiglobus Trappe, Castellano & Amar	2
Gummivena Trappe & Bougher	1
Gymnogaster J.W. Cribb	1
Gymnomyces Massee & Rodway	37
Gymnopaxillus E. Horak	2
Gyrodon Opat.	10
Gyroporus Quél	10
Hallingea Castellano	3
Hebeloma (Fr.) P. Kumm.	~150
Heimioporus E. Horak	16
Hoehnelogaster Lohwag	1
Horakiella Castellano & Trappe	1
Hydnangium Wallr.	3
Hydnellum P. Karst	38
Hydnum Pers.	120
Hygrophorus Fr.	~100
Hymenogaster Vittad.	~100
Hysterangium Vittad.	50
Inocybe (Fr.) Fr.	500
Laccaria Berk. & Broome	25
Lactarius Pers.	~400
Leccinellum Bresinsky & Manfr.	~5
Leccinum Gray	75
Lenzitopsis Malençon & Bertault	1
Leucogaster R. Hesse	20
Leucopaxillus Boursier	15
Leucophleps Harkn.	5
Lindtneria Pilát	11
Lyophyllum P. Karst.	50
Maccagnia Mattir.	1
Mackintoshia Pacioni & Sharp	1
Macowanites Kalchbr.	30
Malajczukia Trappe & Castellano	8
Mayamontana Castellano, Trappe & Lodge	1
Melanogaster Corda	25
Membranomyces Jülich	3
Mesophellia Berk.	4
Multifurca Buyck & V. Hofstetter	5
Mycoamaranthus Castellano, Trappe & Malajczuk	1
Mycolevis A.H. Sm.	1
Naucoria (Fr.) P. Kumm.	~30
Nothocastoreum G.W. Beaton	1
Octaviania Vittad.	15
Paragyrodon (Singer) Singer	1
Paxillus Fr.	15
Paxillogaster E. Horak	1
Phellodon P. Karst.	16
Phylloporus Quél.	~50
Piloderma Jülich	6

Pisolithus Alb. & Schwein.	~12
Podohydnangium G.W. Beaton, Pegler & T.W.K. Young	1
Polyozellus Murrill	1
Polyporoletus Snell	1
Pseudotomentella Svrček	9
Psiloboletinus Singer	1
Pterygellus Corner	5
Pulveroboletus Murrill	25
Ramaria Fr. ex Bonord.	~60
Retiboletus Manfr. Binder & Bresinsky	6
Rhizopogon Fr.	~150
Rhodactina Pegler & T.W.K. Young	2
Rhodogaster E. Horak	2
Rhopalogaster J.R. Johnst.	1
Richoniella Costantin & L.M. Dufour	5
Riessia Fresen.	4
Riessiella Jülich	2
Royoungia Castellano, Trappe & Malajczuk	1
Rozites P. Karst.	20
Rubinoboletus Pilát & Dermek	10
Russula Pers.	~1300
Sarcodon Quél. ex P. Karst.	36
Scleroderma Pers.	25
Scutiger Paulet	1
Sebacina Tul. & C. Tul.	6
Setchelliogaster Pouzar	6
Setogyroporus Heinem. & Rammeloo	1
Sinoboletus M. Zang	5
Sistotrema Fr.	4
Stephanopus M.M. Moser & E. Horak	5
Stephanospora Pat.	4
Strobilomyces Berk.	20
Suillus Gray	50
Thelephora Fr.	49
Timgrovea Bougher & Castellano	5
Tomentella Pers. ex Pat.	75
Tomentellopsis Hjortstam	5
Torrendia Boidin & Gilles	2
Trechispora P. Karst.	46
Tremellodendron G.F. Atk.	8
Tremelloscypha D.A. Reid	1
Tricholoma (Fr.) Staude	~200
Truncocolumella Zeller	3
Tubosaeta E. Horak	5
Tulasnella J. Schröt.	46
Turbinellus Earle	5
Tylopilus P. Karst.	~75
Tylospora Donk	2
Veloporphyrellus L.D. Gómez & Singer	2
Xanthoconium Singer	7
Zelleromyces Singer & A.H. Sm.	17
Zygomycota Moreau	
Endogone Link	~20
Peridiospora C.G. Wu & Suh J. Lin	4
Sclerogone Warcup	1
Youngiomyces Y.J. Yao	2

Note: The number to the right shows the number of known species belonging to the corresponding genus.

including glucanase, cellulase, chitinase, which are indicators of the large and diverse metabolic processes. It is believed

that there are possibilities of degradation of polymers found in the upper soil horizons which are rich in organic matter. This means that *L. bicolor* is particular saprotroph, i.e. it is optional mixotroph and this is a proof, which is already found in ecological studies, that there is no clear distinctive border in the way of nutrition. At some stage of their life cycle they can adapt to the habitat, according to their underlying genetic mechanism that largely determines the amplitude of the ecological plasticity.

Three years later, the genome of *Tuber melanosporum,* another ectomycorrhizal fungi, but hypogeous and from phylum Ascomycota, was entirely sequenced. The result shows very different characteristics comparing to *L. bicolor* sequencing, i.e. the particular behavior exhibited by *Tuber* may be a symptom of a not yet perfected system of mutual symbiosis in some ectomycorrhizal ascomycetes (Martin et al 2010). From the comparison of the genomes of the basidiomycete *L. bicolor* and of the ascomycete *T. melanosporum*, it is evident that the mycorrhizal symbiosis has evolved in divergent pathways in these totally different systematic groups.

For a long time it has been known that among the most common of ectomycorrhizal fungi are these from phylum Ascomycota and the most common among them is *Cenococcum geophilum* Fr. It is found in large geographical areas (Fig. 4 and Fig. 5), especially in temperate latitudes, and it is associated with a large number of autotrophic plants (Gymnospermae and Angiospermae) from sea level to high altitudes (2000 m a. s. l.), but not in overmoisturized soils (Nedelin, unpublished data). A lot of studies demonstrated its dominant role in various ectomycorrhizal communities. This fungus does not form true sporophores as it belongs to the anamorphic (imperfect) fungi but black oval structures with a size of about 1 mm, which are densely intact with interwoven hyphae (microsclerotium, Fig. 5.1, black arrow head with white outline). Despite its high prevalence its ecological role is not yet fully understood, or as Mikola (1948) wrote (Smith and Read 2008) in his monograph on ecology and physiology of *Ceno-*

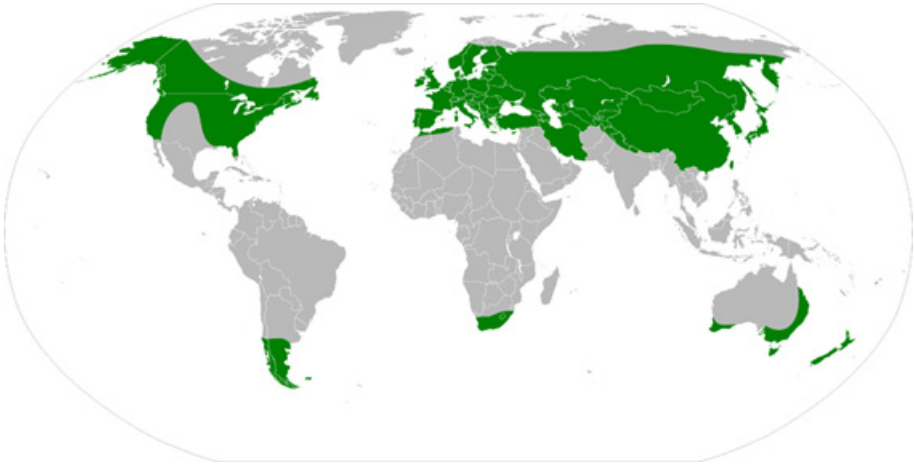

Fig. 4. Worldwide distribution of Cenococcum geophilum (Anonymous 2014).

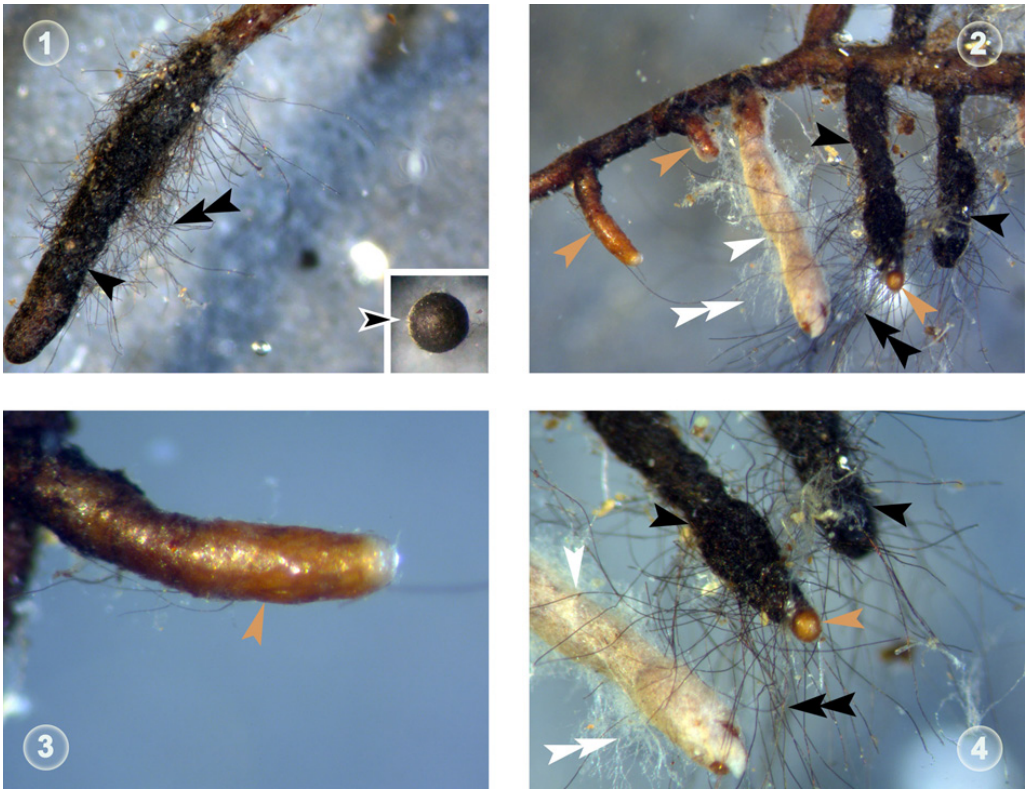

Fig. 5. Ectomycorrhiza on the roots of Picea abies with Cenococcum geophilum.

coccum geophilum: 'Whether *Cenococcum* is useful to its plant – symbiotroph as other useful ectomycorrhizal fungi is not clear'. It has been found that *C. geophilum* is extremely drought tolerant (Orcutt and Nilsen 2000) and this raises a hypothesis that the partnership in the formation of ectomycorrhizal mycocoenosis at dry conditions will increase. This gives us reason to believe that its role in the global climate change, particularly in the global warming, will be significant.

Figure 5 presents results of our own studies. The fine black mycelia threads (double black arrow heads) of *Cenococcum geophilum* ectomycorrhiza (black arrow head) out of the mantle compact soil near ectomycorrhiza and protect both plant and fungus from drought. These threads are visible with naked eye and can serve also as an inoculum (Fig 5.1). Very often there are more species on the tree and even on particular root as we can observe directly but mostly in different stage of development (some of them are not functioning and even dead, but the fungal inoculum is very often active). On the root of this *Picea abies* we can find at least three different ectomycorrhizal morphotypes, referring to three different ectomycorrhizas (Fig 5.2 and Fig. 5.4). The white one in the center (Fig. 5.2, white ar-

row head) has clearly visible extraradical mycelium (white double arrow heads) and is well developed and fully functional. The right next to it (*Cenococcum geophilum* with the ochraceous orange tip) is old, the mantle is probably inactive, but the root is alive. From the tip of this ectomycorrhiza a new one emerge (Fig. 5.4, orange arrow head). It is unusual from *Cenococcum geophilum* ectomycorrhizas to grow another ones, the opposite in most cases is more often but as we see this sometimes happens and the most important factors are the availability of other active ectomycorrhizas near root tips or root buds (Fig 5.3) and the favorable conditions for development of particular species.

Among the most popular and studied ectomycorrhizal fungi from Ascomycota are these of genus *Tuber*, taxonomically in order Pezizales. They are about 60 species hypogeous fungi, mainly distributed in the Northern Hemisphere. At the end of 20th century attempts have been made, partly successful, to be introduced in New Zealand (Hall et al. 1994). Truffles belong to three different geographical regions – Southeast Asia, North America and Europe, with a major center of distribution – the Mediterranean region. The most valuable species in Europe is the white truffle from Piedmont – *Tuber magnatum* Pico and the black truffle from Périgord – *Tuber melanosporum* Vittad. Despite the progress of science and incredible efforts of experts, cultivation of the first is still almost impossible. This is due to the very specific ecological niche (Mediterranean climate and specific macro- and microstructure of the soil, pH 7–8), and probably the surrounding microbial environment that influences further development and preservation of ectomycorrhiza and for formation of ascomata. Studies showed for *T. melanosporum* (Hall et al. 1994), that after inoculation, the photobionts increase their dry weight and size compared to the uninfected plants. The herbaceous vegetation around them dries and circles of dead vegetation called 'brulé' can be observed. This is most as a result of a phytotoxic action produced by the truffle mycelium, which affects the soil environment by killing some microorganisms (Pacioni 1991).

Structural Elements of the Ectomycorrhiza

Hartig net

Hartig net is made by hyphae that lead to its development from the inner layer of the mantle and grows between the cells of the cortical layer of root tips, without penetrating the cell walls. The main function of Hartig net is the bidirectional exchange of water with solutes and carbohydrates from the plant. This is achieved by complex, labyrinth-like branching hyphae, wherein the contact area is increased significantly and with the aid of enzymes that partially dissolve the outer layer of the cell wall, wherein the hyphae are 'wedge' between the cells of the plant roots. The presence of cytoplasm, rich in organelles is an evidence of dynamic metabolic processes. Hartig net can be observed by colorization with Chlorazol black E stain and Nomarsky DIC microscopy.

Mantle

The largest relatively constant structure is the mantle (mycoclena). It covers the outer part of ectomycorrhizal root tips and

constitutes 20–40 % of the biomass of ectomycorrhiza and its morphological structure is defined by mycobionts, photobionts and to a lesser extent by other factors like soil and climatic conditions (Harley and McCready 1952). In most of the ectomycorrhizal fungi, three layers are well distinguished: outer, middle and inner. Usually, the inner layer is compact, and branches intensively toward the root cortex in order to better exchange of nutrients, such as the hyphae are densely intertwined. The outermost one is often looser. Very often in the empty space between the hyphae are accumulated phenolic compounds and polysaccharides that serve subsequently for various metabolic processes (Peterson et al. 2004). Mantle cells envelope the root of its outer surface, and come in direct interaction with the soil. Functional properties of the mantle are the result of its different structure. The mantle of the ectomycorrhizal fungi barred a root from the soil environment. In this way it acts as a physical barrier, but because morphologically and physiologically the fungal cell differs from the plant, all the advantages of the first are used by the plant. For instance, an important one is to restrict the downward flow of synthesized carbohydrates, located in the cells of the plant to the ground, where there is a drying in depth in a drought season. In general, the movement of water, mineral salts and carbohydrates is according to a physical law of the fluids – osmosis/diffusion, i.e., the direction of movement is from a higher to a lower concentration. This can be detrimental to the plant sometimes. Reduction of losses regulated by mantle fungal hyphae that exhibit selective bidirectional permeability. They are able to absorb glucose and fructose from the root cells by converting them through the enzymatic processes into digestible for the plants carbohydrates and glycogen. The latter can be stored for long periods in the mantle hyphae and can serve as nutritive reserve.

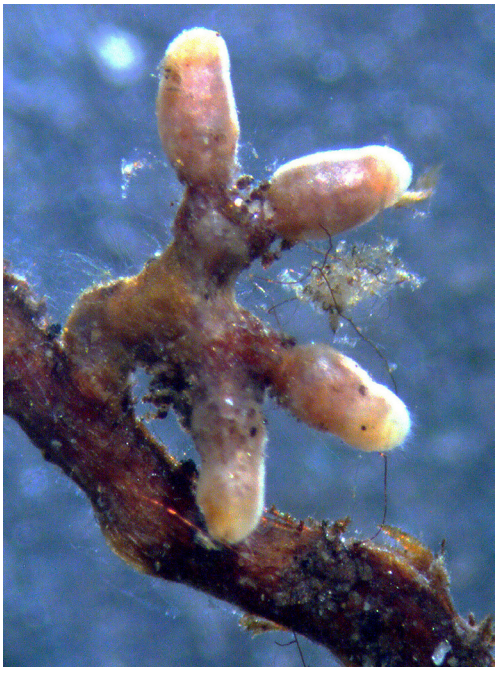

Fig. 6. Semi-transparent mantle in dichotomy branched mycorrhiza in *Pinus sylvestris.*

The mantle morphological and anatomical features are the basis for 'Colour Atlas of ectomycorrhizae' (Agerer 1986–2008). It was built on the ability of a fungus to form unique ectomycorrhizal patterns with one plant genus with a constant structure. Important morphological features for the differentiation of the mantle are: visibility of outer mantle layer (Fig. 6), cell organization type, presence of milky substances, cystidia and others. Agerer (1991, 1995) distinguished nine types plectenchymatous and seven types pseudoparentchymateous structure of the

mantle. The study can be done at different levels (Brundrett et al. 1994) – via dissecting and compound microscope, by a specialized microscopy – polarizing, Nomarski differential interference contrast microscopy (DIC), fluorescent and confocal, transmission – electron microscope (TEM) and scanning electron microscope (SEM). The last clearly differentiate the topography of external hyphae of the mantle. For a more detailed study it is necessary to combine more methods of microscopy. Another reason is that only the most thorough study of the ectomycorrhiza can make possible a reliable identification under natural conditions.

One of the most difficult to study processes is ectomycorrhizal morphogenesis. In past two decades due to the rapid development of molecular methods and efforts of researchers, many of phases are clarified enough to outline pathway from embryonic root stage to well-developed ectomycorrhiza. It is known that first, the precolonization events occurred in molecular level, then microclena is formed, hyphae are placed the intracellular space and, at last, extraradical mycelium develop (Smith and Read 2008). From this time the ectomycorrhiza begin to function in full capacity and its longevity was estimated to be about 4 months in the *Paxillus involutus* (Batsch ex Fr.) Fr. or *Tylospora fibrillosa* (Burt) Donk *Picea sitchensis* (Bong.) Carr. systems (Downes *et al.* 1992). One of the most interesting phenomena is cell death during ectomycorrhizal morphogenesis. The recent studies show, that during the pre-symbiotic phase in *Tuber* ectomycorrhiza formation, progressive accumulation of polyphenol deposits developed in epidermal and cortical cells, leading to the cell death (Ragnelli et al. 2014). This unexpected cell death, observed in healthy mycorrhiza (both in fugal and plant partner) need to be further investigated and will be one of the key points for human influence on forest ecosystems.

Extraradical mycelium and common mycelial network

For the greatest importance of ectomycorrhiza is the extraradical mycelium, which usually varies or changes seasonally, and the emanating from mantle structures – rhizomorphs, sclerotia and others. In various ectomycorrhizal fungi the extraradical mycelium differs, sometimes considerably, according to the fungus – plant combinations and soil conditions, but the most important thing they have in common is the crucial role in the functioning of forest ecosystems.

Hyphae, developing from the outside of the mantle into the surrounding soil are forming the extraradical (extramatrical)[2] mycelium. Although studies under natural conditions are difficult, the experiments in Plexiglas containers, rhizotrones or root windows with natural or artificial substrate can provide useful information about its growth and development (Egli 1991). There is already sufficient evidence showing that the extraradical mycelium grows and colonizes substrates most commonly forming a spatial fan-shaped frame of the hyphae in the soil, extending to tens of centimeters from the plant root. Moreover, it connects them to each other, and makes a network between the roots of individual plants of one or of different species, most frequently of the same family (Kennedy 2005). This depends on the phytobiontic spectrum for the particular

[2]According to Agerer there is a difference between extraradical and extramatrical mycelium.

ectomycorrhizal fungus. When several compatible mycelium unite together, they form a common mycelial network that is capable to carry out transmission of water and minerals in different directions, but most often, to the plant, which suffers from deficiency (Read and Boyd 1986). Sometimes the hyphae produced sticky substances, the product of their metabolism, which have different functions as the most important of these is the adherence of soil particles to each other and to the hyphae. This is especially important for improving the structure of sandy soils and the increase of water retention ability. They are also able to penetrate into the soil colloidal particles, affecting favorably the soil structure. For instance – in clay and heavy soils they separate them while in sandy soils act compacting. Read (1992) has estimated that in 1 cm^3 of soil, the length of these hyphae in *Pisolithus arhizus* (Scop.) Rauschert exceeds 200 m, as is often their thickness are comparable to the cross-section of a cell. When the rock below the upper soil horizons is reached, the extraradical mycelium is able to affect it destructively. It is because of small cracks that are in the rock formed by the secretions of organic acids and the penetration of hyphae inside. Some of the minerals then become available for absorption by the plant to perform its vital functions (Peterson 2004).

The natural environment of extraradical mycelium is a part of the soil, which in turn is also a natural habitat for various soil microorganisms. That is why there is a complex effect on the soil as they enhance or decline its conditions to a certain degree.

Very often it has been observed on the surface of the extraradical mycelium various aggregations of bacteria, fungi and other saprothrophs in different layers of the soil. Studies show, that their role in the formation and functioning of ectomycorrhiza are not fully understood, but the experiments raise a hypothesis, that some of them help in the formation of mycorrhiza, others for their functioning and third have negative effects (Tarkka and Frey-Klett 2008).

The extraradical mycelium grows most often seasonally, but some authors confirmed that it can develop slowly even in winter in evergreen species – 0.44 mm per day for *Thelephora terrestris* Ehrh. (Coutts and Nicoll 1990). The growth rate per day in the active season can reach up to 4 mm, and in some combination of fungus-plant even more. The different seasonal growing trends of each ectomycorrhizal fungus affect to the ectomycorrhizal composition below and above ground. In this dynamic process the extraradical mycelium serves as a primary inoculum in the soil for colonizing new rootlets. For revealing of the functional role ectomycorrhizal fungi play, it is critical to compare the ratio of the hyphae length, which sets up the extraradical mycelium, compared to the total root system length. This can serve as an indicator of soil colonization degree and the potential for absorption by the plant. In different species, the results vary quite widely and sometimes are very impressive – from 200 to 8000 m of hyphae·m^{-1} roots (Read and Boyd 1986). There is an attempt done by Weigt et al. (2012) to standardize the values of spatial distribution of extraradical mycelium in soil, according to different types suggested by Agerer (2001). Some terms, quantifying the extraradical mycelium are accepted as a standard: Specific Potential Mycelial Space Occupation (sPMSO) – the exploration type specific complete area that is covered

by the ectomycorrhizal mushroom systems ($mm^2 \cdot cm^{-1} \cdot ECM^{-1}$), Specific Actual Mycelial Space Occupation (sAMSO) – the projection area of mycelial systems ($mm^2 \cdot cm^{-1} \cdot ECM^{-1}$), Specific Extramatrical Mycelial Length (sEML) ($m \cdot cm^{-1} \cdot ECM^{-1}$), and Specific Extramatrical Mycelial Biomass (sEMB) ($\mu g \cdot cm^{-1} \cdot ECM^{-1}$).

Morphological structures of the extraradical mycelium

The extraradical mycelium forms different structures in natural habitats. The most important of them are: rhizomorphs (hyphal treads), sclerotia, asexual and sexual reproductive organs – fruiting bodies (sporophores – ascomata and basidiomata).

The term 'rhizomorph' is usually primarily used to describe the linear aggregations of parallel-oriented hyphae in wood-decomposed fungi (e.g. *Armillaria melea* (Vahl) P. Kumm., *Serpula lacrymans* (Wulfen) P.Karst., etc.). Unlike them, in the ectomycorrhizal fungi, these structures are not expressed so clearly in a morphological and structural manner and are not typical rhizomorphs but resembling them. Not every cord can be named rhizomorph and in ectomycorrhizal fungi, they are placed in several categories, according to their anatomical and functional structure. Morphology, color, internal composition and the type of ornamentation of calcium oxalate crystals are the most important features for their determination (Agerer 1986–2008). The study of rhizomorphs and cords shows that the interwoven of the hyphae are different in the species in a cross-sectional view. In more complex of them, one or more central hyphae are enlarged and extended up to the central cavity, which function is the transportation of water and minerals. External hyphae are thickened with pigmented walls and perform mostly two functions – providing sufficient strength and flexibility, and prevent water loss during the transport.

Unlike the rhizomorphs, the thicker hyphal mycelial cords take an intermediate position according to the terms of morphology – between rhizomorphs and sucking hyphae. In most of the ectomycorrhizal fungi, sclerotia are rare and only appeared in certain species. It is a compact mass of hardened fungal mycelium containing food reserves. It is almost formed from the extraradical mycelium, but in some cases originated from rhizomorphs or emanating hyphae grown from the mantle. At a later stage of development, when it reaches maturity, the outer surface of sclerotium is covered by densely intertwined cells similar to a cortex. In the central hyphae of the sclerotia are deposited reserve substances such as polysaccharides, lipids, and polyphosphates. Almost always in favorable or unfavorable (under the stress) conditions from sclerotia, where they are available, according to the genetics of species, are developed spore-forming epigeous or hypogenous structures, as well as hyphae, which may subsequently form mycorrhizas. Their relative long durability is making them a suitable source for the preservation of the fungal cultures of the species under laboratory conditions and can be used for further research or other purposes (Brundrett et al. 1996).

Usually, under the occurrence of combination of a favorable conditions – suitable temperature, soil and air humidity, CO_2 concentration and the availability of nutrients, obtained from the host plant, the hyphae of extraradical mycelium grow and intersect at certain places just below the surface or below the upper soil horizon and form primordia. They

give the beginning of the special spore-forming structures – sporophores or most commonly known – fruiting bodies, which are very diverse in terms of morphology. Since last name is associated with the development of flowers and fruit in plants and is used in botanical sense, it is conceptually wrong, but it became more popular (Courtecuisse and Duhem 1995). Their proper name is ascoma (pl. ascomata) when they belong to Ascomycetes (Ascomycota) and basidioma (pl. basidiomata) if they belong to Basidiomycetes (Basidiomycota).

Ecological and Physiological Aspects of Ectomycorrhiza and Their Functional Role in Ecosystems

Fungal ectomycorrhizal component, typically act advantageously to the plant, especially in a poor soil conditions, where a deficit of one or more vital elements exists. The hyphae of the extraradical mycelium can reach considerably greater distance comparing to the fine sucking roots. They are able to overcome the zone of deficit for a particular macro- and microelement (Read, 1991) and supply it to the plant in the form of aqueous salt ions. In return, the plant give to ectomycorrhizal fungus ready to digest carbohydrates (sucrose or glucose+fructose depending on the ability to produce autonomously invertase by fungus) that are products of the photosynthesis. The effect for the plant is a result from the balance of synthesized by plant products on one hand, and the quantity of the basic components used for photosynthesis, on the other (Agerer et al. 2012). It is obvious that this problem is a challenging and a complex task because it depends on many factors variable in space and time.

Because of the diversity and different ecological niches occupied by both plants and fungi involved in ectomycorrhiza, there is a significant difference in the transport capacity of nutrients as well as different effects on growth of tree species involved in it (Burgess et al. 1994). This applies not only to the extent of colonization of the roots, but also for the development of hyphae of the species in the soil.

Agerer (2001) has classified the exploration types of ectomycorrhizal fungi, according to their structural elements and development differences based on the extraradical mycelium and now several exploration types are well recognized:

1) contact exploration type – only a few emanating hyphae occurs;

2) medium-distance exploration type – with three subtypes:

2.1) fringe subtype, which form fans of emanating hyphae and rhizomorphs,

2.2) mat subtype with the undifferentiated rhizomorphs or slightly differentiated,

2.3) smooth subtype with rhizomorphs with a central core of thick hyphae;

3) long distance exploration type – this type has a few but highly differentiated rhizomorphs of type F[3];

4) pick-a-back.

In the evolutionary aspect, the first

[3]Acording to Agerer, 1986–2008, there are six type of ectomycorrhizal rhizomorphs:
a) Undifferentiated rhizomorphs with a loosely woven hyphae with several hyphae grow not parallel;
b) Undifferentiated rhizomorphs with compact arranged hyphae, growing parallel;
c) Slightly differentiated rhizomorphs with a little enlarged central hyphae;
d) Differentiated rhizomorphs with randomly distributed thick hyphae;
e) Highly differentiated rhizomorphs with a central core of very thick septate hyphae;
f) Highly differentiated rhizomorphs with a central core of very thick partially or completely hyphae.

types are more primitive, while long distance exploration type of the soil is the most complete. Pick-a-back type is not so widespread. Typically it often produces haustoria in the cortical cells of the root, and grows in association with other ectomycorrhizal types. The proposed classification is used by a number of authors in their mycocoenological studies. The presence of several types of exploration ectomycorrhiza with one plant allows a greater utilization of the available resources on one hand and on the other – a more efficient cover of the ecological niches of ectomycorrhizal fungi. Establishment of the exploration types made by Agerer (2001) has a great practical role for the quantifying and qualifying the ability of ectomycorrhiza to improve tree growth.

Extraradical mycelium, which spreads into the soil, can colonize it in considerable distances. Rhizomorphs of *Pisolithus arhizus* can connect saplings of *Pinus* at distance of about 42 cm and in long distance exploration type – more than 70 cm (Schramm 1966). In a study of the transfer of radioactive carbon isotopes *in situ*, there is an evidence of bidirectional nutrients exchange between *Betula papyrifera* Marshall and *Pseudotsuga menziesii* (Mirb.) Franco, through a common mycelial network composed of several extraradical mycelia belonging to one fungal species, forming ectomycorrhiza with both plants (Simard et al. 1997). In this experiment, there was a variable amount of transfer of ^{14}C in the direction from *Betula papyrifera* to *Pseudotsuga menziesii*, that vary from 6 % to 23 %, depending on the percentage of exposition to light 100 % (full) or partially. In the first case, the transfer is the greatest, and this experiment shows clearly that the plant species are able to adapt better and are more stable if they grow as a community than as single individuals.

The function of extraradical mycelium for nutrients transportation has been established by a number of authors, who demonstrated the correlation between development stage, rhizomorphs type and quantity of transported phosphates in them. Due to its limited surface area and the small contact with the surrounding mycorrhizosphere the mantle plays a relatively limited role in obtaining nutrients, so the emanating hyphae and rhizomorphs significantly increase the volume of explored soil and the nutrients uptake takes a place mostly thanks to them.

The fundamental ecological importance of ectomycorrhiza is mainly for supporting of the plant with water and dissolved mineral salts by higher absorptive capacity of hyphae and the much larger area compared to this of fine roots; protection from pathogens; soil improved structure; degradation of the main rocks by organic acids released from the hyphae and reduction of adverse pollution effect by decomposition and transformation of toxic molecules for humans to non-toxic compounds.

Conclusion

The ectomycorrhizosphere plays a key role for plants, especially those in forest ecosystems, which grow under physiological stress due to various abiotic and biotic factors. Ectomycorrhiza is actively involved in the carbon cycle. According to classical studies from Read (1991) at least 10 % of it is used by ectomycorrhizal fungi for their growth and development. The dynamics of the distribution of ectomycorrhizal ecological niches in time and

space significantly affects the appearance of plant communities in the boreal region.

The studying of ectomycorrhiza is almost 130 years old. For the past two decades it reached a new quality stage and the modern molecular methods shed new light on the distribution, structure and size of various populations in different habitats and phylogenetic relation between species.

The benefits from ectomycorrhiza are proven experimentally and are no longer matter of debate. For several decades in a lot of countries, for afforestation purpose, on nutrient limited soils are used specially inoculated (often with several ectomycorrhizal species) seedlings. Disadvantageous effects of pollution, mainly from heavy metals in soils with anthropogenic impacts can be reduced and the vitality of weakened woody plants with conservation significance enhanced by the introduction of additional ectomycorrhizal inoculum. The synthesis of ectomycorrhiza and subsequent success can be achieved only on the basis of deep knowledge of ectomycorrhizal fungi biology, their photobiotic spectrum and appropriative soil and climatic characteristics of the terrain.

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DYNAMIC THIRD-GENERATION WHOLE-STAND MODEL FOR SCOTS PINE PLANTATIONS IN BULGARIA

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Abstract

The main objective of this investigation was to derive a dynamic third-generation whole-stand model, which consists of a flexible system of mathematical equations presented graphically – Stand Density Management Diagram (SDMD) – and allows good description of the development of the stands over time. A new SDMD for Scots pine plantations in Bulgaria was elaborated that included two improvements as compared to the preceding SDMD. The Natural thinning curves (NTC) sub-model was presented in a dynamic equation form and was estimated over repeated measurements data from permanent sample plots. The Equivalent height curves (EHC) sub-model was reformulated to include a site index-specific parameter, which produced SDMDs differentiated by site index classes. The principal sub-models of the SDMD were fitted with high level of determination and produced unbiased and statistically significant parameter estimates. The NTC in generalized algebraic difference equation form provided the maximum possible model flexibility by means of stand-specific shape and asymptote of these trajectories. The slope parameter of the self-thinning asymptotes α had value of 1.74. The new model improvements added to its precision and assured improved predictive abilities.

Key words: dynamic growth model, *Pinus sylvestris,* stand density management diagram, Scots pine plantations, stand-specific model parameters, whole-stand model.

Introduction

A model is an abstraction, or a simplified representation, of some aspect of reality and the forest growth model is an abstraction of the natural dynamics of a forest tree or stand, which may encompass growth, mortality, and other changes in stand composition and structure (Vanclay 1994). According to the level of detail they provide, forest growth models are classified into three categories: whole-stand, size-class and individual-tree models. In Bulgaria only whole-stand growth models have been developed and characteristic of this model category is the idea of modeling stand growth by the age development of mean and cumulative stand variables such as height, standing volume or volume growth for use in the assessment, planning and implementation for forestry operations (Pretzsch 2009). The whole-stand growth models are the oldest model type, and are largely represented

by the growth and yield tables. Pretzsch (2009) distinguished four generations of whole-stand growth models and the growth and yield tables for normal stands currently implemented in the forest management in Bulgaria can be classified as second generation stand-level models. They present in tabular form the most important stand characteristics according to established silvicultural prescriptions in homogeneous even-aged managed "normal" stands, usually every 5 years.

Besides the traditional for the American and the European forestry practice table form, other whole-stand growth models have been developed and presented for practical application in graphical form. Such models are the Stand Density Management Diagrams (SDMD), which were initially developed in Japan and are primarily used to derive density-control schedules by management objective. The methodology of the SDMD was modified and adapted for application in Bulgaria and was implemented in development of such models for Scots pine plantations in Rila Mountain (Stankova 2004) and for Scots pine and Austrian black pine plantations on national scale (Stankova 2006). These Stand Density Management (or Control) Diagrams are composed of 5 elements, which are defined by principal stand growth parameters (Stankova 2006): Equivalent height curves (EHC), which describe the relationship between stand yield and density at a given growth stage; Full density line, which connects the points of density–maximum yield combinations; Natural thinning curves (NTC), which describe the yield growth of stands of given initial densities with time-lapse, considering the process of self-thinning; Equivalent mean diameter curves (EDC), which connect yield-density combinations of stands having the same mean diameter; and Yield index lines, which are parallel to the Full density line and indicate different stocking levels.

The SDMDs can be subdivided into (1) static, which lack a temporal density decrease sub-model, and (2) dynamic, which include a sub-model for density decrease in time (Newton 2009b). The density decrease sub-model included in the dynamic SDMD usually requires supplementary information about stand age and/or site index (Castedo-Dorado et al. 2009, Newton 2009a, 2012a, 2012b), which is not directly obtainable from the diagram. Another approach in modeling the dynamic component of the SDMD is to express directly volume or biomass growth in time as a function of the decrease in density (Tadaki 1964, Shibuya et al. 1997, Stankova and Shibuya 2007) in a set of natural thinning trajectories, thus bypassing the sub-model of density decrease with time. In spite of the intrinsically dynamic nature of the SDMD developed in Bulgaria, their dynamic sub-model – the Natural thinning curves – was not estimated over repeated measurements data from permanent sample plots, but was indirectly determined from the parameters of the full-density line (Stankova 2006, Stankova and Shibuya 2007); this sub-model showed potential for precision improvement (Stankova 2007). An investigation on the accuracy of the Equivalent height curves through validation with experimental data sets suggested possibility to improve their predictive abilities through SDMD differentiation by site index classes (Stankova and Petrin 2008).

The main objectives of the present investigation are: 1) to reformulate the

NTC sub-model of the SDMD in dynamic equation form; 2) to derive site index-specific EHC sub-model, and 3) to apply the improvements in the elaboration of a new dynamic SDMD model for Scots pine (*Pinus sylvestris* L.) plantations in Bulgaria.

Materials and Methods

Data set

The data set was generated from both personally collected and published data records. The first source of data comprised 115 variable-sized (of circular or rectangular form) temporary sample plots established and measured in 2002–2005. In each plot, breast height diameters of all trees, samples of average and dominant tree heights and the number of trees were recorded. Mean and dominant stand heights, stand basal area and stand density, expressed as number of trees per hectare, were calculated from the plot measurements. The mean and the total stand volumes were calculated from the individual stem volumes of the trees within each plot, which were determined through the volume tables for Scots pine plantations by Krastanov et al. (1983). Beside the personally recorded data, additional data from 340 plots in *P. sylvetsris* plantations either published or granted by other researchers were included in the data set. The sources of these data are permanent and temporary sample plots data published in PhD theses, MSc thesis, books, articles, and research reports (Stankova 2006, Appendix 2). Data records from 21 permanent sample plots installed in 1–3 replications and re-measured 1 to 3 times were obtained from Forest Inventory Plans. In addition, 46 measurement sets used for developing growth and yield tables for Scots pine plantations in Bulgaria (Krastanov et al. 1980) were also included as part of the parameterization data set. Dominant heights for the published data were additionally determined using the established allometric relationship to the mean height for Scots pine plantations (Stankova et al. 2006). Data sub-sets that contained the dependent and all independent variables, required by the respective sub-model, were drawn from the total data set to parameterize each particular principal sub-model of the SDMD. Both longitudinal and cross-sectional data were used to fit the EDC sub-model and the EHC sub-model. Dominant heights were grouped into 1 m classes for the EHC sub-model. Site index was estimated by plots for reference age 50 years, according to the dynamic site index model by Stankova and Diéguez-Aranda (2012) and data were classified into four-meter site index classes. Three of them – 16, 20 and 24 m – presented sufficient amount of data for parameterization of the EHC sub-model, which was assessed through a preliminary screening. Data within each site index class were examined by height classes and only those height classes, which had at least 3 measurements and revealed adequate estimation of the reciprocal relationship between density and mean volume (Stankova 2006), with 2 positive model parameters, were included in the parameterization data set. The dominant height classes, which were finally selected, spanned uniformly the density mean volume data for each of site index

classes 16, 20 and 24 m (Table 1). The estimation of dynamic NTC requires longitudinal data and measurements from 48 permanent plots were available for it. To overcome the scarce amount of data for this sub-model, 81 more plots (initial density sub-set) were added. Two measurements in time were available for each plot of the latter sub-set, the first-one representing the initial planting density coupled with initial mean volume value, which was set equal to zero. Summary of the parameterization data sets by sub-models is shown in Table 1.

Table. 1. Descriptive statistics of the data sets used to parameterize the principal sub-models of the dynamic SDMD.

SDMD Sub-model	Stand variable**	Mean	Standard Deviation	Minimum	Maximum
Equivalent Mean Diameter Curves (*n*=609)	Quadratic mean diameter, cm	14.8	6.9	2.2	38.0
	Dominant stand height, m	14.7	6.1	1.5	32.5
	Stand density, ha^{-1}	2986	2451	360	20000
	Total stand volume, $m^3 \cdot ha^{-1}$	295.1	174.9	2.2	909.7
Equivalent Dominant Height Curves	**Site index 16m (*n*=57)**				
	Dominant height class, m	11	4	5	15
	Stand density, ha^{-1}	4152	2888	1505	20000
	Mean stem volume, m^3	0.0710	0.0499	0.0029	0.1936
	Site index 20m (*n*=204)				
	Dominant height class, m	13	6	4	27
	Stand density, ha^{-1}	3597	2544	466	16800
	Mean stem volume, m^3	0.1308	0.1613	0.0018	1.1578
	Site index 24m (*n*=90)				
	Dominant height class, m	16	5	6	22
	Stand density, ha^{-1}	2925	2300	553	12550
	Mean stem volume, m^3	0.1632	0.1295	0.0056	0.4884
Natural Thinning Curves*	**Permanent Sample Plots (*n*=133)**				
	Stand density, ha^{-1}	2375	2384	393	20000
	Mean stem volume, m^3	0.2893	0.2488	0.0029	1.2568
	Initial density sub-set (*n*=162)				
	Stand density, ha^{-1}	4827	3187	1723	20000
	Mean stem volume, m^3	0.0353	0.0513	0	0.2441

Note: * – ***n*** for the NTC sub-model denotes plot – measurement occasion combinations;
** – the dependent and independent variables of each sub-model are included.

Dynamic SDMD model derivation

The new dynamic SDMD for Scots pine plantations provides improvements to the preceding model (Stankova 2006, Stankova and Shibuya 2007) in two ways. First, the NTC sub-model was reformulated from integral to generalized algebraic difference equation form, thus deriving a dynamic equation to be estimated over a data set from repeated measurements of permanent sample plots. Next, the EHC sub-model was reformulated to include a site index-specific parameter, providing in this manner different SDMD model for each site index class.

The integral equation form of the NTC sub-model is suggested by Shibuya (1995) and presents the mean stem volume as a function of the number of trees per hectare:

$$v = K \cdot N^{-\alpha} - f \quad (1),$$

where: v is the mean stem volume (m^3), N is stand density (ha^{-1}), and α, K and f are parameters. Parameter f by definition is stand-specific and depends on the initial stand density, while parameters K and α correspond to the intercept and the slope of the full-density line (Shibuya 1995). The latter two parameters are often considered species-specific, i.e. global model parameters, but some studies suggest that the intercept K is not a global, but a specific parameter, which depends not only on the tree species, but also on site quality, species mixture and stand origin (Shibuya 1995, Weiskittel et al. 2009). In this study, we assumed that α is global, while K is site-specific. At the initial stand conditions, mean stem volume approaches zero, while N obtains the initial stand density value N_0:

$$K \cdot N_0^{-\alpha} - f = 0 \Rightarrow N_0^{\alpha} = \frac{K}{f} \sim f(X) \quad (2)$$

Equation 2 suggests that, if there is a complex unobservable independent variable X, which combines the effect of variables otherwise not accounted for in the model (e.g. initial stocking rate, soil conditions, ecological and climatic factors) and which is incorporated in the natural thinning model, the two specific model parameters K and f should be related to it in an inverse manner. Thus, the following reciprocal formulations are suggested:

$$K = p \cdot X, f = \frac{1}{X} \quad (3),$$

where p is a global model parameter. By substitution of equations 3 into equation 1 and after solving for the initial conditions $N=N_1$ and $v=v_1$ the following expression for X is obtained:

$$X = \frac{v_1 + \sqrt{v_1^2 + 4 \cdot p \cdot N_1^{-\alpha}}}{2 \cdot p \cdot N_1^{-\alpha}} \quad (4)$$

After substitution of equation 4 into equation 1 for the current conditions $N=N_2$ and $v=v_2$, the Generalized Algebraic Difference Approach (GADA) equation is derived:

$$v_2 = p \cdot X \cdot N_2^{-\alpha} - \frac{1}{X} = \frac{N_1^{\alpha} \cdot N_2^{-\alpha}}{2}\left(v_1 + \sqrt{v_1^2 + 4 \cdot p \cdot N_1^{-\alpha}}\right) - \frac{2 \cdot p \cdot N_1^{-a}}{v_1 + \sqrt{v_1^2 + 4 \cdot p \cdot N_1^{-\alpha}}} \quad (5)$$

Equation 5 provides prediction for the mean stem volume, based on the stand density value (N_2) and the past records for the mean stem volume and stand density (N_1, v_1).

The EHC sub-model is based on the reciprocal equation by Hagihara (2000):

$$v = \frac{1}{At \cdot N + B} \quad \text{or} \quad V = \frac{N}{At \cdot N + B} \quad (6),$$

where: V is the total volume per hectare ($m^3 \cdot ha^{-1}$), while At and B are model parameters that are functions of time, but independent of density:

$$At = \frac{1}{v_0 \cdot N_i^*}\left(e^{-(\alpha-1)\mu\cdot\tau} - e^{-(1-\mu)\tau}\right) \quad (7)$$

$$B = \frac{e^{-\tau}}{v_0} \quad (8),$$

where: v_0 is a constant irrespective of the initial density and is equal to the initial mean stem volume, τ is called biological time (an integrated value of the coefficient of growth $\lambda(\tau)$ with respect to physical time t), μ is a specific constant corresponding to the relative mortality rate as τ tends to be finitely large, N_i^* is the initial density of a population that obeys the 3/2 power law of self-thinning from the start of the experiment (Hagihara 2000). Equation 8 can be reformulated as:

$$e^{-\tau} = B \cdot v_0 \quad (9)$$

Substitution of equation 9 into equation 7 allows the following formulation of At as a function of B:

$$At = \frac{1}{v_0 \cdot N_i^*}\left[(B \cdot v_0)^{\mu(\alpha-1)} - (B \cdot v_0)^{1-\mu}\right] =$$
$$= \frac{v_0^{\mu(\alpha-1)}}{v_0 \cdot N_i^*} B^{\mu(\alpha-1)} - \frac{v_0^{1-\mu}}{v_0 \cdot N_i^*} B^{1-\mu}$$
$$\Updownarrow$$

$$At = c_1 \cdot B^{d_1} - c_2 \cdot B^{d_2} \quad (10),$$

where:

$$c_1 = \frac{v_0^{\mu(\alpha-1)}}{v_0 \cdot N_i^*} \quad (11)$$

$$c_2 = \frac{v_0^{1-\mu}}{v_0 \cdot N_i^*} \quad (12)$$

$$d_1 = \mu(\alpha - 1) \quad (13)$$

$$d_2 = 1 - \mu \quad (14)$$

Next, the representation of parameter B as a power function of the dominant height class ($\hat{H}$, m) was considered (Stankova and Shibuya 2007):

$$B = a_2 \cdot \hat{H}^{-b_2} \quad (15),$$

where: a_2, b_2 are model parameters. The output of a preliminary fit of the reciprocal equation 6 over the experimental data, i.e. the estimates for parameter B through equation 6, was used to examine the power relationship of equation 15. It was fitted once setting b_2 global and a_2 site index specific parameter and then setting a_2 global and b_2 site index specific parameter. The results showed that parameter a_2 was not significant when fitted as specific parameter, while parameter b_2

varied significantly by site index classes. Consequently, parameter a_2 was derived as global, while parameter b_2 – as specific model parameter.

After substitution of equation 10 into equation 6, the EHC sub-model was expressed as a function of two independent variables (dominant height class and number of trees per hectare), five global (c_1, c_2, d_1, d_2 and a_2) and one (b_2) site index specific parameters:

$$v = \frac{1}{N(c_1 \cdot B^{d_1} - c_2 \cdot B^{d_2}) + B},$$

where $B = a_2 \cdot \hat{H}^{-b_2}$ (16)

The other sub-models of the dynamic SDMD followed the formulations suggested in the previous studies (Stankova 2006, Stankova and Shibuya 2007):

Equivalent mean diameter curves sub-model:

$$V = \frac{\pi \cdot N \cdot QMD^2 (a \cdot H + c)}{40000} \quad (17)$$

Full density line:

$$v_{FDL} = K \cdot N^{-\alpha} \quad (18)$$

Yield index lines:

$$v_{YIL} = YI \cdot v_{FDL} \quad (19),$$

where: H is dominant stand height (m), QMD is stand quadratic mean diameter, a and c are global model parameters in an expression that derives average stand form height as a linear function of dominant stand height (equation 17), *YI* denotes yield index that corresponds to the stand stocking rate and obtains values between 0 and 1, v_{FDL} denotes the mean stem volume of stands on the full density line, while v_{YIL} denotes the mean stem volume of stands of yield index *YI*.

Estimation procedure and goodness of fit statistics

The estimation procedure required application of a sequence of several steps for model parameterization. First, the dynamic NTC sub-model was fitted in algebraic difference equation form (equation 5), using a similar method to the Base-Age Invariant (BAI) dummy variable approach (Cieszewski et al. 2000), that exhibits invariance property of the parameter estimates. The BAI methods are proposed and developed where dominant height is the dependent variable and stand age is the independent variable, but was adapted here for a model formulation in which stand density is the independent variable and mean stem volume is the dependent variable; therefore, it is a "Base-Density Invariant (BDI)" method. The mean stem volume corresponding to the base density was estimated as plot specific parameter employing dummy variables p_i of value 1 for plot i and 0 otherwise. Next, the value of the global slope parameter α estimated through equation 5 was used to constrain the value of parameter d_1 against d_2 in the EHC sub-model (equation 16). If parameter μ in equation 14 is expressed by parameter d_2 and is further substituted into equation 13, the following relationship is derived:

$$d_1 = \alpha - 1 - (\alpha - 1) d_2 \quad (20)$$

Consequently, the estimated value for α allows reduction in the number of parameters of equation 16 through imple-

mentation of equation 20 as a constraint. Equations 11–14, on the other hand, propose the following formulation for the constant v_0 (corresponding to the initial mean stem volume at the time of stand establishment):

$$v_0 = \left(\frac{c_1}{c_2} \right)^{\frac{1}{d_1 - d_2}} \quad (21)$$

The values of the model parameters c_1, c_2, d_1, d_2 can be constrained in a way that v_0 attains practically meaningful value by employing an appropriate empirical constant, e.g.

$$v_0 = \left(\frac{c_1}{c_2} \right)^{\frac{1}{d_1 - d_2}} < 0.0005,\ m^3 \quad (22)$$

The constant 0.0005 m^3 was obtained from the volume tables for Scots pine plantations (Krastanov et al. 1980) and corresponds to the mean stem volume of a tree of 1cm diameter at breast height from the lowest height classes (12–15 m). Parameter b_2 was expanded to include dummy variables (q_i) and parameters associated with the particular site indices (b_{2i}), i.e.

$$b_2 = \sum_{i=16,20,24} q_i \cdot b_{2i} \quad (23),$$

where q_i are the dummy variables of value 1 for site index *i* and 0 otherwise. After fitting the EHC sub-model (equation 16) with simultaneous application of the derived constraints (equations 20 and 22), the initial mean stem volume at the time of stand establishment v_0 was estimated from equation 21 and subsequently substituted in the initial density data subset for the NTC sub-model (Table 1). Then, the NTC sub-model was refitted over the updated data set, which did not change the slope parameter value *α* to the second decimal place, but provided more precise estimation for parameter *p* (equation 5). The GADA form of the NTC sub-model suggests stand-specific shape (*f*) and intercept (*K*) of the estimated trajectories, thus deriving set of polymorphic curves with multiple asymptotes (Figure 1). The uppermost of the resultant asymptotes was defined as the Full density line, i.e. $v_{FDL} = K_{FDL} \cdot N^{-\alpha}$, $K_{FDL} = \max(p \cdot X)$. The elaboration of the dynamic SDMD was completed with the estimation of the EDC sub-model through equation 17.

The three principal sub-models of the SDMD (EHC, EDC and NTC) were fitted through nonlinear least squares method, applying the Marquardt estimation algorithm. The combined time-series cross-sectional nature of the remeasurement data used to fit the EHC and the EDC contributed to manifestation of heterogeneous variances (heteroscedasticity), which was detected through graphical and analytical tests, and application of Heteroscedasticity-Consistent Covariance Matrix Estimation (HCCME) (Long and Ervin 2000) was applied to assure the efficiency of the regression estimates for these two sub-models. Furthermore, the assumption of independent errors is very likely to be violated in estimating dynamic regression equations with data from repeated measurements of permanent sample plots (e.g. the NTC). However, the graphical and analytical tests for presence of heteroscedastic errors

did not provide evidence for violation of this regression requirement regarding the data set for estimation of the NTC. Tests for the presence of serial correlation, on the other hand, might be inadequate, because forest stand data do not usually constitute a single series (e.g., the present study), but rather a multiplicity of concurrent, relatively short time series (*sensu* Gregoire 1987). The lack of indisputable evidence for violated requirements to the residuals, together with the earlier-mentioned scarcity of the parameterization data for this sub-model, prevented us from application of any specific corrections while fitting this regression model (equation 5).

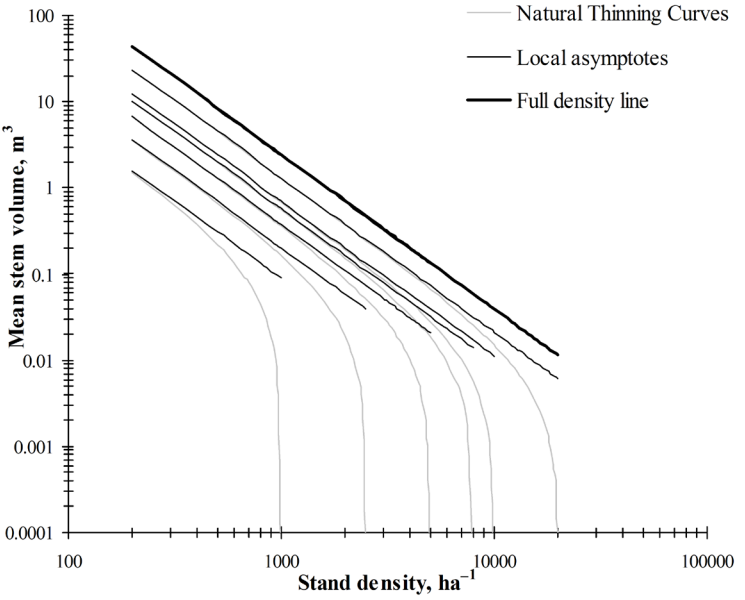

Fig. 1. Natural Thinning Curves sub-model.

The goodness-of-fit of the principal sub-models was assessed on the basis of the adjusted coefficient of determination (R^2_{adj}), the Root Mean Square Error (RMSE), the *Bias* and the %*Bias*:

$$R^2_{\text{adj}} = 1 - \frac{(n-1)\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{(n-k)\sum_{i=1}^{n}(y_i - \bar{y})^2} \quad (24)$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n}} \quad (25)$$

$$Bias = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{n} \quad (26)$$

$$\%Bias = \frac{\bar{y} - \bar{\hat{y}}}{\bar{y}} 100 \quad (27),$$

where: y_i and $\hat{y}_i$ are observed and predicted values of the dependent variable (mean stem volume *v* for NTC and EHC and total stem volume *V* for EDC) on the *i*th plot, *n* is the sample size, *k* is the number of model parameters, $\bar{y}$ is the mean ob-

served and $\bar{\hat{y}}$ is the mean predicted value of the dependent variable.

We further assessed the predictive abilities of the models by considering the 95% confidence (*CI*), prediction (*PI*) and tolerance (*TI*) error intervals:

$$95\%\ CI = Bias \pm \frac{S \cdot t_{0.975}}{\sqrt{n}} \quad (28)$$

$$95\%\ PI = Bias \pm S \cdot t_{0.975} \sqrt{\left(1 + \frac{1}{n}\right)} \quad (29)$$

$$95\%\ TI = Bias \pm S \cdot g\left(1-\gamma, n, 1-\alpha\right)$$

for $1-\gamma = 1-\alpha = 0.95$ (30),

where: *S* is the standard deviation of the errors, $t_{0.975}$ is the 0.975 quantile of the *t* distribution with *n*–1 degrees of freedom, the function g (1–γ, *n*, 1–α) is the tolerance factor tabulated for specified values of *n,* α and γ and provides that the estimated interval will contain at least (1–γ) 100 percent of the future error distribution with probability (1–α). The model bias was additionally assessed by linear regressions of observed against predicted values of the dependent variable and simultaneous *F*-test for line slope equals 1 and zero intercept (Gadow and Hui 1999).

Results

The principal sub-models of the SDMD were fitted with high level of determination (R^2_{adj} above 0.9 for all three sub-models) and produced unbiased and statistically significant parameter estimates (Table 2). The %*Bias*, which indicates by how much the mean of the predictions deviates from the observed mean, obtained values of less than 1 % for all sub-models. The plots of the predictions against the observations, supported by the analytical simultaneous *F*-test, which examines the null hypothesis that the regression line between them has slope equal to 1 and intercept equal to zero, confirmed the goodness-of-fit of the three principal sub-models (Figure 2).

Three sets of EHC were estimated, each of them corresponding to a different site index class (Figure 3) and designated by differing value of the exponent for parameter B (equation 23), which obtained decreasing and statistically significant estimates (Table 2). The slope parameter of the self-thinning asymptotes α had value of 1.74, while the intercept of the Full density line was K = 333867.193.

Discussion

Considering the classification by Pretzsch (2009), the Stand Density Management Diagrams of this study can be categorized as a third generation whole-stand model. Pretzsch (2009) defines that the core element of the third generation stand-level models consists of a biometric model in the form of a flexible system of mathematical equations that are normally transferred to computer programs and predict stand development in relation to a specified management regime, site index and yield level. Although presented and utilized in the form of complex charts, which carry information on the spatial-temporal dynamics of the principal stand-level growth and yield attributes, the SDMD are based on a system of mathematical relationships

Table 2. Goodness-of-fit estimates for the principal sub-models of the dynamic SDMD.

Sub-model	Model fit				Parameter estimation				Error intervals					
					Global parameter estimate		Standard error	*t*-value	Confidence interval		Prediction interval		Tolerance interval	
	R^2_{adj}	[a] RMSE	[b] Bias	Percent bias, %										
NTC	0.950	0.0475	0.0003	0.2322	α	1.7394	0.1018	17.092***	–0.0034	0.0048	–0.0693	0.0708	–0.0742	0.0756
					p	3347.6	1518.7	2.2043*						
EHC	0.938	0.0358	–0.0011	0.8713	c_1	0.0346	0.0024	14.585***	–0.0023	0.0051	–0.0686	0.0714	–0.0730	0.0758
					c_2	0.0335	0.0025	13.159***						
					d_1	0.4245	3.20×10^{-7}	1.33×10^{6}***						
					d_2	0.4263	3.09×10^{-7}	1.38×10^{6}***						
					a_2	24166	1.28×10^{-5}	1.88×10^{9}***						
					b_2	*SI 16*	3.3122	0.1028	32.228***					
						SI 20	3.2950	0.1064	30.964***					
						SI 24	3.2025	0.0620	51.630***					
EDC	0.985	21.116	–0.2930	–0.0568	a	0.4082	0.0050	80.8692***	–2.52	0.84	–42.33	40.64	–44.30	42.61
					c	1.6764	0.0866	19.3472***						

Note: * – Significant at $P < 0.05$; *** – Significant at $P < 0.001$; [a] – RMSE and Bias for NTC and EHC are measured in m^3; while for the EDC in $m^3 \cdot ha^{-1}$; [b] – the absolute biases are not significantly different from zero.

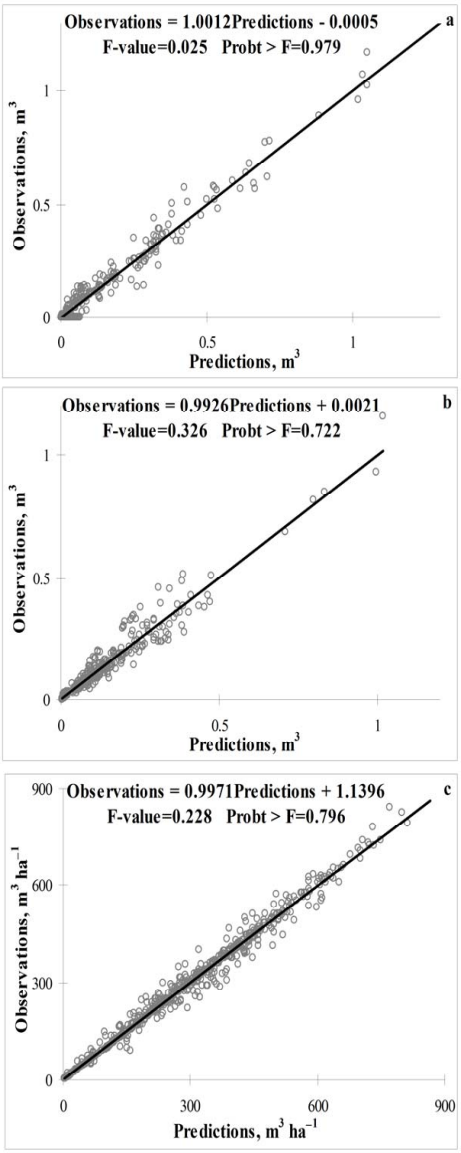

Fig. 2. Plot of observed against predicted values for the principal sub-models: a) NTC; b) EHC; c) EDC.

Note: Linear regressions of observations against predictions are fitted and the results from simultaneous *F*-test for line slope equals 1 and zero intercept (Gadow and Hui 1999) are shown in the plots.

(Stankova and Shibuya 2007, Castedo-Dorado et al. 2009, Newton 2009a), which allow also model incorporation and its further utilization through a computer program (Newton 2012a, 2012b).

García (1988) defined two principal types of growth models: static and dynamic growth models. The static models attempt to predict directly the course over time of the quantities of interest (volumes, mean diameter) and can give good results for unthinned stands, or for stands subject to a limited range of standardized treatments (García 1988). The earlier version of the SDMD for Scots pine plantations (Stankova 2006, Stankova and Shibuya 2007) appeared to be static third-generation whole-stand model, because its density decrease sub-model in time was estimated in integral equation form. Dynamic growth models, on the other hand, predict the rates of change under various conditions, with the time trajectories obtained by adding or integrating these rates. They are needed for forecasting over a wider range of tending regimes and provide a better description of the development of the stand over time than static models (García 1988). To make use of the advantages of the dynamic growth models over the static, a dynamic NTC sub-model was developed in this study. The generalized algebraic difference equation form derived here provides the maximum possible flexibility of this set of curves, because allows stand-specific shape and asymptote of the natural thinning trajectories.

The NTC sub-model expresses directly volume growth in time as a function of the decrease in density (equations 1 and 5) and bypasses the density-decrease sub-model. Such approach for growth projection in time, however, does not include the time variable, expressed through age or

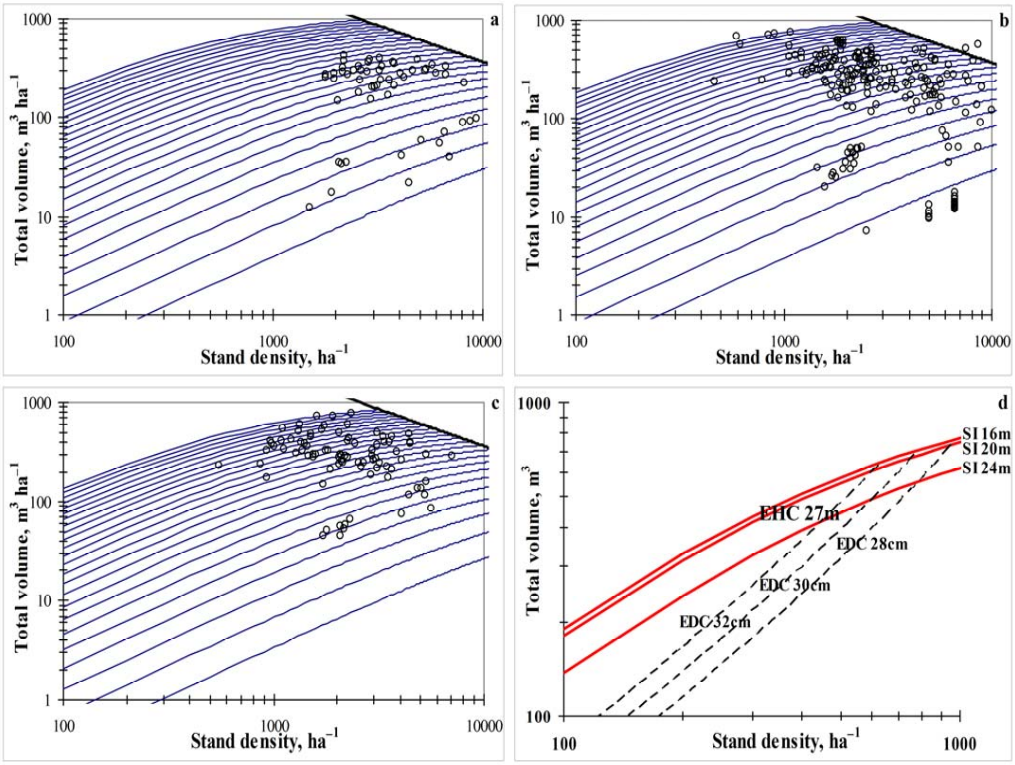

Fig. 3. Equivalent Dominant Height Curves differentiated by site index: a) Site index 16m; b) Site index 20 m; c) Site index 24 m; d) Comparison of EHC for dominant height class 27 m by Site indices.

Note: The parameterization data sets are indicated by circles, Equivalent Height Curves (EHC) by solid lines and Equivalent Diameter Curves (EDC) by dotted lines.

some measure of tree size that is itself a function of time. Thus, if no density decrease occurs in the stand, which can be characteristic for the first (before the onset of the competition-induced mortality) and the last (the phase of growth-resources equilibrium) phases of stand growth, no alteration in the tree size with the progress of time can be predicted. This is not an issue for the Scots pine plantations, which are characterized by relatively high initial densities (over 1000 seedlings per hectare), where competition-induced mortality commences soon after plantation establishment. However, in case of intensively grown plantations of low initial densities, which are managed at short rotation periods and practically do not undergo density-dependent mortality during their life span, this growth model would be inapplicable.

The EHC sub-model of the present study was differentiated by site indices by specifying one of the model parameters as site index-specific. Table 2 shows that the exponent b_2 obtains decreasing with the site index class values and the difference is particularly pronounced for site

index 24 m. Considering equation 16, this parameter trend suggests that mean and total stem volume will obtain lower values for higher site index for the same values of dominant height class and stand density, which is seen also in Figure 3. The same dominant height is attained at earlier age by more productive (high site index) stands than by stands of low growth potential from low quality forest sites. Consequently, the more advanced age for attainment of the same dominant height by stands of lower site index can be viewed as related to bigger overall stem size, moreover the temporal trends of height and diameter differ. This explanation is supported by the assertion of Weck (sensu Assmann 1970) that a given stand height is accompanied by a given total increment which is higher the longer it takes the stand to reach this given height. In agreement with this statement, the total crop volume for a particular height (e.g. dominant stand height 27 m, Figure 3d) is expected to be larger if this height is reached at a later age, i.e. for the lower site quality classes (Figure 3d). Also, dominant height increment is insignificantly influenced by the process of thinning (natural or man-made) and consequently reflects merely the height growth trend of the dominant trees. The stand mean diameter growth, on the other hand, is a result of both the tree diameter growth and the mortality of thinner and weaker trees, which artificially inflates the value of the mean stand diameter. Thus, the mean stand diameter can be expected to have steeper growth gradient than the stand dominant height. The differing mean stand diameter values as a possible explanation of the observed distinctions between the volumes of the EHC of different site indices is also easily derivable from the EDC sub-model (equation 17) and is well illustrated on Figure 3d. Indeed, the quadratic mean diameter estimated for stands of the same dominant height class and stand density, but having lower site index value (16 or 20 m) exceeds by about 2 cm the mean diameter of the stands of higher site index value (Figure 3d). This finding agrees with the conclusion by Assmann (1970) that even in geographically small regions, a uniform relationship of total volume on stand height cannot be assumed and the large observed differences in the yield level are determined by differences in the basal area increment and the local basal area potential of the stands for a given mean height.

Conclusions

A new SDMD for Scots pine plantations was elaborated, which presents a dynamic third-generation whole-stand growth model. The NTC sub-model was reformulated into dynamic equation form and was estimated over repeated measurements data from permanent sample plots, which allowed better description of the development of the stands over time as compared to the former static SDMD. The EHC submodel was reformulated to include a site index-specific parameter, which produced SDMDs differentiated by site index classes that added to the model precision and assured its improved predictability. The newly elaborated dynamic SDMD is applicable for estimation of the stand-level growth parameters at any stand growth stage and for simulation of alternative thinning regimes in accordance with a preferred management objective, with projection of the future stand growth and evaluation of the intermediate and total harvest. Incorporation of the model into software is planned to facilitate its implementation as a management tool.

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APPLICATION OF GEOGRAPHICAL INFORMATION SYSTEM FOR MAPPING FIRE RISK AND DESIGNING FOREST ROADS

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Abstract

Fires are one of the most important disturbances in forests and they damage them. This study was conducted to classify fire risk for a deciduous forest and to predict the locations of forest stands for which fire control operations are required. Normalized Difference Vegetation Index (*NDVI*) and Moisture Vegetation Index (*MVI*) were extracted from satellite imagery of *IRS* LISS III and Landsat 7 ETM$^+$, respectively. Altitude, slope aspect and slope gradient maps were obtained from a digital elevation model using surface analysis in ArcMap. Buffers were created from 0 to 300, 300 to 600, 600 to 900 meters and over 900 meters along the road and around the cattle pens as zones with different levels of fire risk. All the thematic layers were then integrated using the overlay procedure in GIS. Results from the analytical hierarchy process showed that vegetation indices were given the largest weight. The influence of slope gradient on fire behavior was assessed the third largest weight. Slope aspect was assigned the same weight as to slope gradient. The distance from roads and cattle-pens was evaluated with the fourth largest weight. 25 % of the forest area is classified as area with very high degree of vulnerability to fire. This class is generally distributed in the entire region, while areas with very low fire risk are found in the northern parts.

Key words: AHP, GIS, fire risk map, Hyrcanian forest, satellite imagery.

Introduction

One of the main causes of destruction in recent years are wildfires (Gromtsev 2002). The growth of seasonal temperatures also has increased the number of spontaneous wildfires in the predominantly forested areas (Köse et al. 2008). Forest fires are responsible for some devastating damages such as loss of biodiversity, reduction of forests, alteration of landscape, soil degradation, increase in the greenhouse effect, etc (Tuia et al. 2008). The forest fire could influence the soil micro arthropod assemblage in two ways: directly killing by the blaze and indirectly – altering the arthropods' habitat by changing the composition of forest vegetation or disturbing the balance of soil chemicals, water levels, and soil pH. In addition, burning out of leaf litter and other organic matter may cause the depletion of food source of soil arthropods since decomposers are closely associated with those organic substrates (Kim and Jung 2008). In Turkey, forest fires are still one of the greatest natural hazard problems. Last six decades,

1.504.245 ha of forests has been affected by fire (Chuvieco and Salas 1996). Smith et al. (2005) showed that, in the case of Savanna fires, surface spectral reflectance increases with the increasing of fire severity due to the formation of increasing quantities of white mineral ash. Also, their studies showed linear relationships between fire duration and post-fire surface spectral reflectance, with the optimal relationship being a ratio of the 450 and 2034 nm spectral reflectance observations.

The effects of fire on forest ecosystems are different according to their characteristics (Bowmana et al. 2008). But in general, by determining the fire risk zone, the type of fire and its intensity, the duration, size, power and the season in which it has occurred, it is possible to control fire damage (Podur et al. 2002, Fulé et al. 2008). The most common fires in Mazandaran natural resources in Hyrcanian zone of Iran are small (less than 0.5 hectare) and superficial, caused by people (unintentionaly). Local distribution of fires in the province show that fire frequency in the province increases from east to west. In 2006, 49.36 % of all fires have occurred just in Sari, Neka and Behshahr. The analogical share in 2005 was 73.82 %. Therefore, governments should use funds from their fire suppression budgets for fire alert activities. Early warning systems should keep the population aware of the risk of fires in critical periods, and the use of open fires should be absolutely prohibited (Ritchie et al. 2007).

The regime of fires Fire regime in the Hyrcanian deciduous forests is poorly understood but it has been largely inferred by the fire traits history. In the present study, an attempt was made to prepare a forest map of fire risk zones by integrating a satellite image, topographic and other thematic maps from a geographic information system (GIS) for the Miana forest which is covering the sensitive to forest fires areas in Iran.

Materials and Methods

Description of the study area

Measurements were carried out in the Miana forest which is situated in the deciduous northern forested part of Iran from 52°56′30″ to 52°59′25″ East longitude and from 36°12′25″ to 36°16′35″ North latitude. A Digital Elevation Model (DEM) was generated with 20-m resolution in ArcMap (Figure 1). Annual

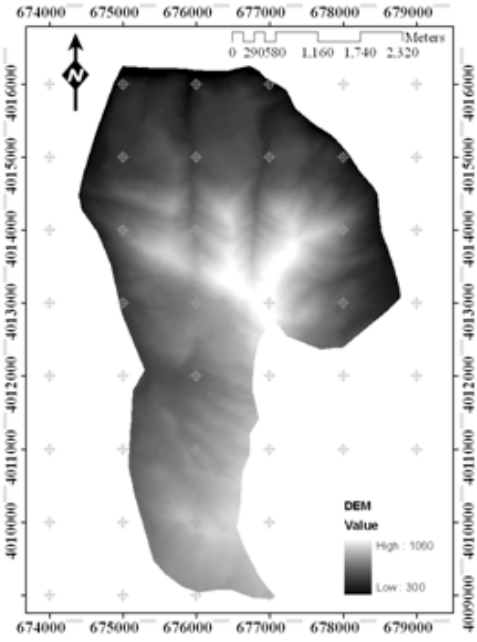

Fig. 1. DEM of the study area.

mean temperature ranges from +12 °C to +14 °C. Annual mean precipitation is between 900 and 1000 mm. The forest altitude ranges from 320 to 1060 m above sea level. Soil textures range from loam to loamy silt and loamy clay. The study area is covered by four kinds of soils, namely non development randzin, washed brown soil with calsic horizon, calcareous brown soil and brown with alkaline soil pH. The bed rock is limestone, calcareous sandstone, marl lime and calcareous conglomerate. The total area of the Miana forest is 1831 hectares. In 1996 a 10800 m long road was provided for this area.

Vegetation indices values

In Normalized Difference Vegetation Index (*NDVI*), the ratio between red (*RED*) and near-infrared (*NIR*) bands is used to emphasize the spectral differences between these bands, showing vegetation conditions (Figure 2a). The *NDVI* was calculated using Equation (1).

$$NDVI = (NIR - RED)/(NIR + RED) \quad (1)$$

Where *NIR* is near infrared band (Band 4) and R is red band (Band 3) of the *IRS* LISS III digital image. The spatial resolution of *IRS* images was 23.5 m and band lengths corresponded to the green, red, near infrared and middle infrared. Landsat 7 ETM$^+$ images with 30 m spatial resolution were used to obtain Moisture Vegetation Index (*MVI*). Using the mid-infrared (*MIR*) band, which is characteristic with lower atmospheric scattering, instead of the red band, may produce higher correlations to vegetation targets on land surface (Equation 2).

$$MVI = (NIR - MIR)/(NIR + MIR) \quad (2)$$

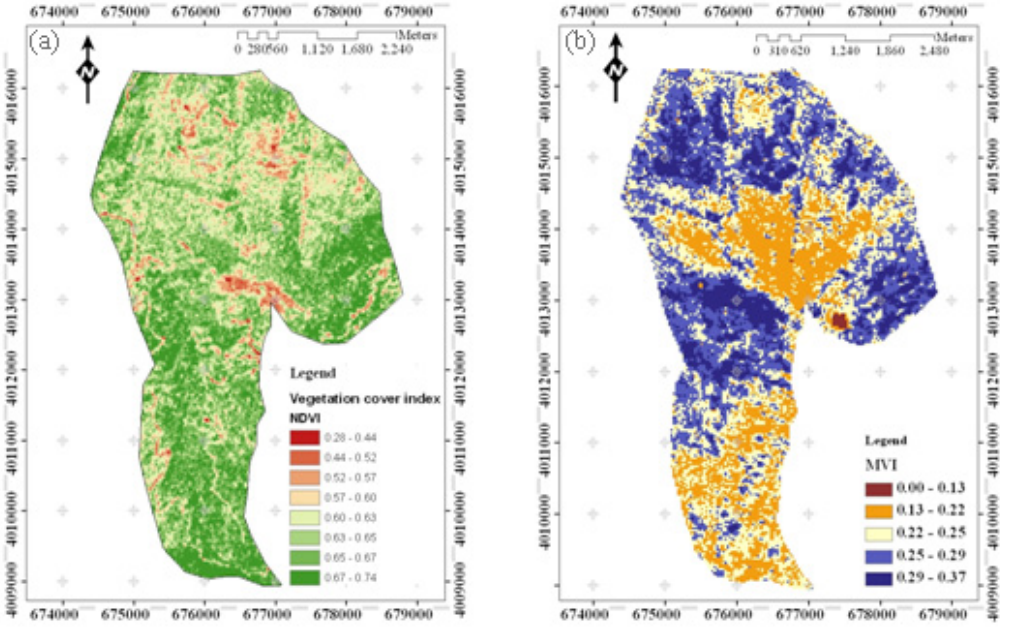

Fig. 2.t Maps of the study area: (a) NDVI and (b) *MVI*.

Where *MIR* is middle infrared band (Band 5) and R is red band (Band 4) of ETM+ sensor (Figure 2b).

Topography

Altitude (Figure 3a), slope aspect (Figure 3b) and slope gradient (Figure 3c) maps

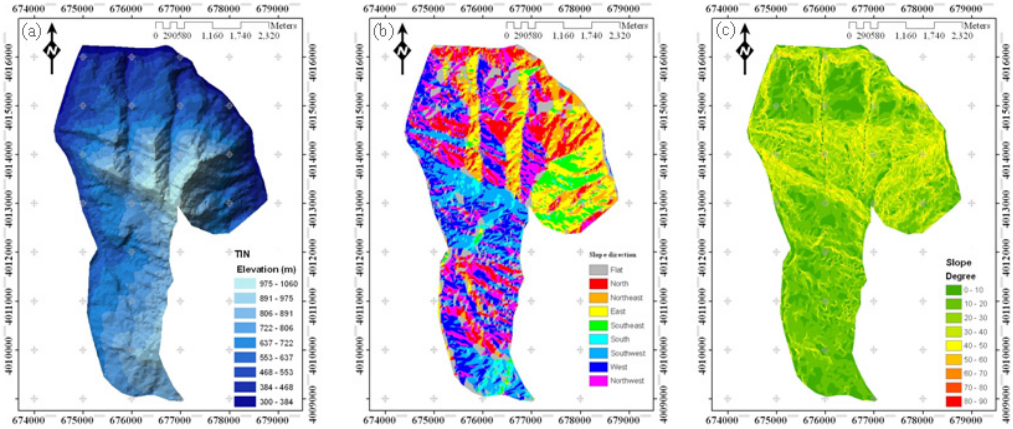

Fig. 3. (a) Altitude, (b) slope aspect and (c) slope gradient maps of the study area.

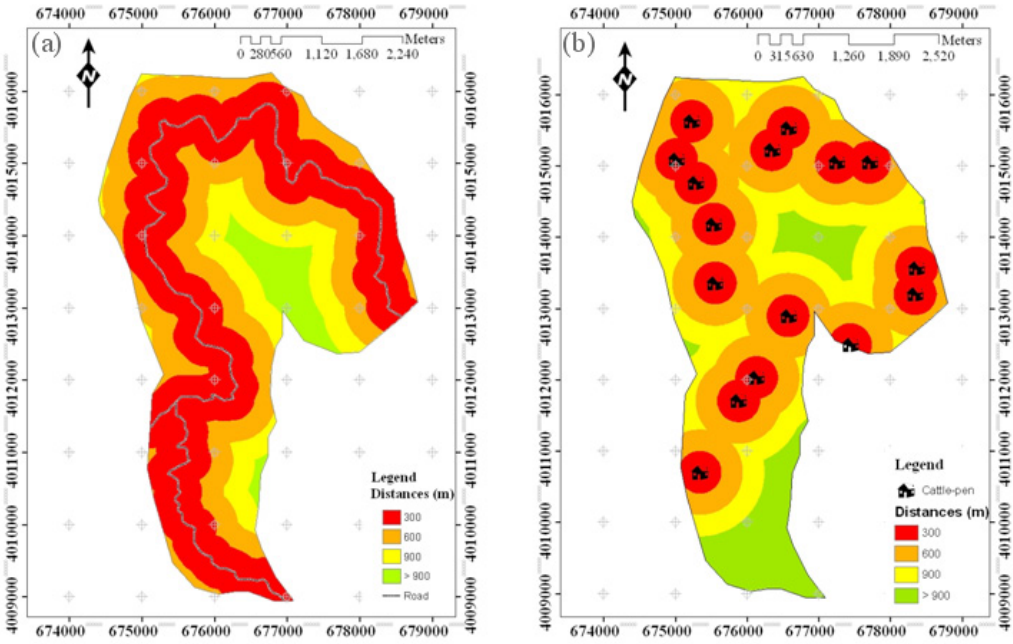

Fig. 4. (a) Road corridor and (b) cattle-pen buffer maps of the study area.

were obtained from the digital elevation model using surface analysis in ArcMap.

Distance from roads and cattle-pens

Forests can be burned in result of the movement of people, animals and vehicles. Thus, forests that are close to roads and cattle-pens are fire prone. Buffers were created from 0 to 300, 300 to 600, 600 to 900 meters and over 900 meters along the road and around the cattle-pens as zones with different levels of fire risk. ArcMap was used for creating such buffer zones along the road (Figure 4a) and around the cattle-pens (Figure 4b).

Determination of factor weights and risk degrees

Expert choice software version 9.5 was used for analytical hierarchy process (Expert Choice Inc 1995). AHP is based on determining the relative priorities of the criteria by pairwise comparison. In this research, by adopting AHP technique with integrating expert opinions, weights of effective factors are quantified by assigning a value from 0 to 9. All the thematic layers were then integrated using the overlay process of GIS. ArcGIS version 9.2 and IDRISI Andes version 15.0 software packages were utilized as basic analysis tools for spatial analysis and data layers manipulation. The equation used in GIS to determine forest fire risk places is:

$$FR = 0.366\ V_M + 0.256\ V_D + 0.121(S_D + S_S) + 0.057\ (D_R + D_C) + 0.022\ E \quad (3)$$

Results

Over 75 % of the total area was represented by areas with vegetation moisture index more than 0.22 (Figure 5). The study area has been covered by forest trees, shrubs

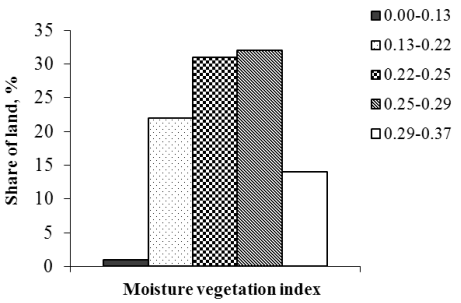

Fig. 5. Distribution of lands covered by different *MVI* classes.

and herbaceous, so the largest part of the region`s area has received NDVI values greater than 0.5 (Figure 6).

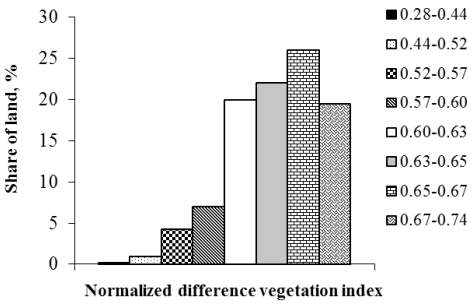

Fig. 6. Distribution of lands covered by different NDVI classes.

Over 70 % of the total area was represented by areas within the altitude range 468–891 meters (Figure 7). The study area includes slopes with all kinds of aspects (Figure 8). The general slope gradient of Miana forest is less than 50 % (Figure 9). Approximately 50 % of the total area is

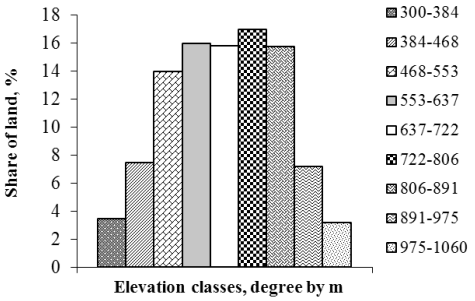

Fig. 7. Distribution of lands in different altitude classes.

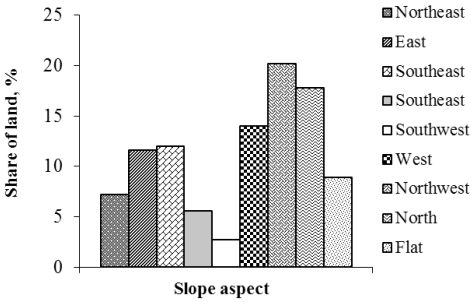

Fig. 8. Distribution of lands in different slope aspects.

within a distance of up to 300 meters from the road (Figure 10). Less than 25 % of the

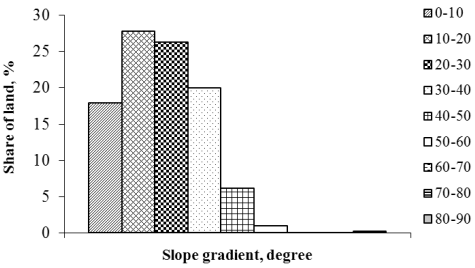

Fig. 9. Distribution of lands in different slope gradient classes.

total area was represented by areas closer than 300 meters to cattle-pens (Figure 11).

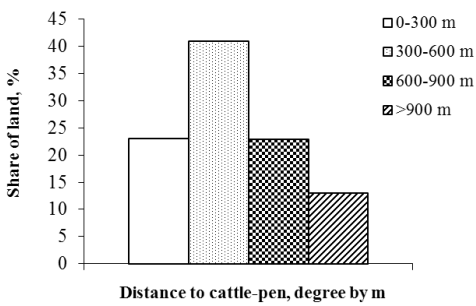

Fig. 10. Distribution of lands by different distances to road.

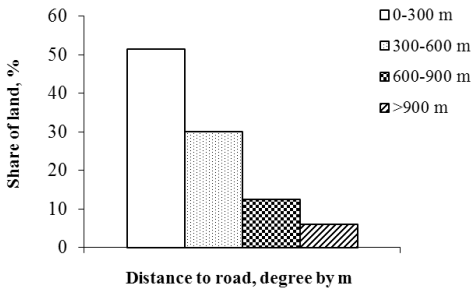

Fig. 11. Distribution of lands by different distances to cattle-pens.

During the analysis, vegetation moisture and of vegetation cover have been assigned the greatest weights because even though an environment may be favourable for a wildfire, fire cannot occur unless fuel is available and vegetation is dry. The impact of slope gradient on fire behaviour was evaluated with the third largest weight. Aspect was assigned equal weight with slope gradient. Since the sunlight is much more reflected by southern slopes, fire breaks out fast and spreads over the southern slopes. Distance from roads and cattle-pens was rated with the fourth largest weight. The risk factor decreases with

increasing distance to these objects. It means that zones that are closer to these places were given a higher rating (Table 1).

The priority as an effective factor for fire occurrence in forests has the plant and soil moisture (0.366) > vegetation cover (0.256) > slope gradient = slope direction (0.121) > distance to cattle pen and road (0.057) > altitude (0.023) (Figure 12). 25 % of the forest area is classified as such with very high vulnerability to fire. This class is generally distributed in the entire region, while areas with very low risk are found in the northern parts (Figure 13). Road designing was done according to the forest fire risk map (Figure 14). Characteristics of forest road networks have been shown in Table 2.

Table 1. Weights and ratings assigned to variables and classes for forest fire risk modeling.

Variables	Classes	Ratings	Variables	Classes	Ratings
Moisture of vegetation cover (weight = 0.366)	0.00–0.13	8	Distance to road in meters (weight = 0.057)	0–300	8
	0.13–0.22	7		300–600	6
	0.22–0.25	6		600–900	4
	0.25–0.29	5		> 900	2
	0.29–0.37	4			
Vegetation cover (weight = 0.256)	0.28–0.44	2	Distance to cattle-pens in meters (weight = 0.057)	0–300	8
	0.44–0.52	3		300–600	6
	0.52–0.57	4		600–900	4
	0.57–0.60	5		> 900	2
	0.60–0.63	6	Slope aspect (weight = 0.121)	Flat	1
	0.63–0.65	7		North	2
	0.65–0.67	8		North east	3
	0.67–0.74	9		East	4
Altitude in meters (weight = 0.022)	975–1060	1		North west	5
	891–975	2		West	6
	806–891	3		South east	7
	722–806	4		South west	8
	637–722	5		South	9
	553–637	6	Slope gradient in degrees (weight = 0.121)	0–10	1
	468–553	7		10–20	2
	384–468	8		20–30	3
Map of fire risk	3.2–4.6	Very low		30–40	4
				40–50	5
	4.6–5.2	Low		50–60	6
	5.2–5.7	Moderate		60–70	7
	5.7–6.2	High		70–80	8
	6.2–7.4	Very high		80–90	9

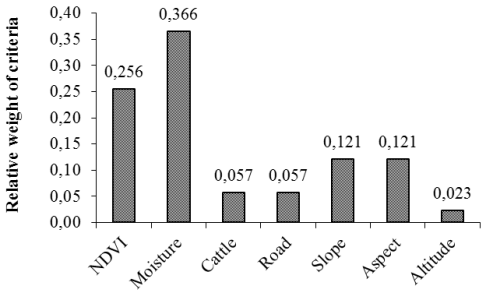

Fig. 12. Derived priorities with respect to effective factors on forest fire.
Note: Inconsistency Ratio = 0.05.

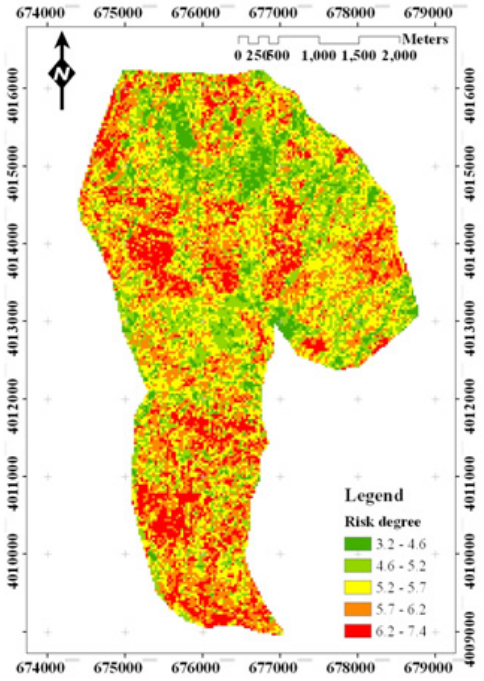

Fig. 13. Forest fire risk map.

Table 2. Technical characteristics of forest road network.

Road density, m·ha^{-1}	Road spacing, m	Skidding distance, m	Road performance, %
14	714	357	63

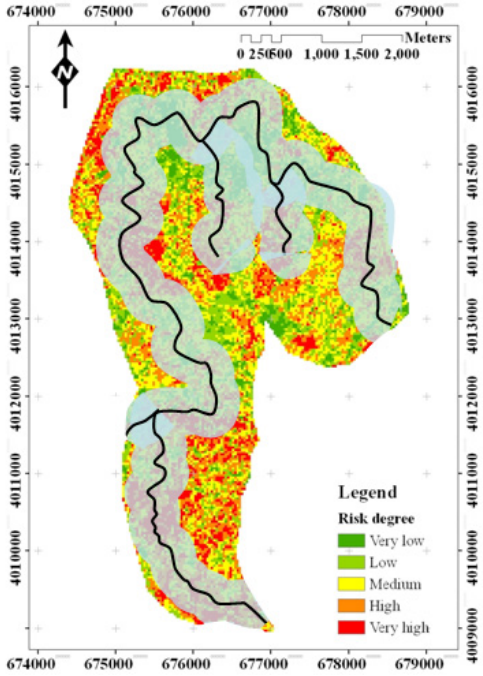

Fig. 14. Designing of access roads to fire risk zone.

Discussion

The use of satellite imagery to measure the impact of fire on vegetation communities has become a popular topic of discussion in recent years (Gromtsev 1996). It has been demonstrated that a relationship between fire severity and soil damage can be deduced in eucalypt forests by fire severity measures an important finding for understanding the interrelationship between wildfire, soil erosion and water quality (Sriboonpong et al. 2001, Shakesby et al. 2007). Zhijun et al. (2009) in a study in Jeilin province of China applied satellite data and GIS techniques to provide new layers from effective factors for forest sensitivity to fire. They showed that the most important effective factor for

a start of a fire is topography and human activity, respectively.

Forest fire risk zones are locations where a fire is likely to start, and from where it can easily spread to other areas (Breece et al. 2008). Anticipation of factors influencing the occurrence of fire and understanding the dynamic behaviour of fire are critical aspects of fire management (Jaiswal et al. 2002). A geographic information system (GIS) can be used effectively to combine different forest-fire causing factors for demanding the forest fire risk zone map (Robert et al. 2001). *MVI* show best performances in dense humid forests, whereas NDVI is a good indicator of green biomass in deciduous and dry forests (Marozas et al. 2007). Satellite data are suitable instruments to introduce and classify forest places when integrating the parameters topography, vegetation cover, vicinity to roads and settlements (Tapias et al. 2004). The integration of this satellite data into GIS can be very useful to determine risky places and to plan forestry management after fire (Erten et al. 2005).

Angayarkkani and Radhakrishnan (2010) have presented an intelligent system for effective forest fire detection using spatial data. The proposed system made use of image processing and artificial intelligence techniques. The images in the spatial data, obtained from remote sensing, have been utilized by the presented system for the detection of forest fires. GIS is very useful and important in forest fire management. GIS plays a critical role in mapping and documenting fire, predicting its course, analyzing alternative fire-fighting strategies, and directing tactics and strategies in the field. GIS can make the information possible to be an input for decisions by establishing a relation among the information (Chuvieco and Congalton 1989).

Conclusion

Minute and complete assessment of fire damages in forests and estimating the starting spread of a fire are possible using a map of forest fire risk zones. This map is produced by integrating satellite images in the data base of a geographic information system (GIS). In this way, collected data include a topographic map, a vegetation map, maps of slope gradient and aspect. Distance from cattle-pens and roads, have been used for understanding the behavior of forest fires and establishing locations where a fire is likely to start and from where it can easily spread to other areas. Therefore, it is necessary to determine the fire risk zones for all forest sites and use these data for a better planning and managing of forests. The experimental results have demonstrated the effectiveness of the proposed integrated system in detecting forest fires using spatial data.

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THE EFFECTS OF FOREST SITE CONDITIONS AND STANDS' AGE ON LITTER MICROARTHROPOD DENSITY AND COMMUNITY STRUCTURE IN ZHYTOMYR POLISSYA, NORTHERN UKRAINE

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Abstract

The effects of forest site conditions and age of stands on absolute density and community structure of litter microarthropods were studied in pine forest in Zhytomyr Polissya, northern Ukraine. Litter samples from cuts, non-closed, young, middle-aged, and mature stands in a mesofilic pine forest (site condition A2) and mesofilic Pinetum compositum (site condition B2) were collected, microarthropods were extracted, counted and identified to main taxa. Mean absolute density of total microarthropods and their main taxa was higher in B2 site conditions for all ages of stands, except the young. Within each type of forest site conditions, litter microarthropod density fluctuated depending on the age of stands. However, the differences in absolute densities for most microarthropod taxa were statistically significant only between stands of distant age groups: between cuts and middle-aged or mature stands. Decreased absolute density of total litter microarthopods, Acari, and Collembola observed in cut sites and non-closed stands may be the result of forest floor disturbance associated with harvesting and decreased litter input. In microarthropod community structure, relative densities of Mesostigmata and Astigmata increased, whereas Collembola density decreased along forest age gradient. The differences were significant in middle-aged and mature stands relative to cut sites.

Key words: forest site conditions, stands, litter microarthropods, absolute density, community structure.

Introduction

Soil and litter microarthropods play an important role in proper functioning of forest ecosystem. They contribute to regulation of decomposition, nutrient cycling, and energy flow (Curry 1973, Seastedt 1984, Lussenhop 1992, Kandeler et al. 1999, Tripathi et al. 2005). Changes to forest floor microarthropod community structure may lead to changes in these processes. Microarthropods are source of food for predators (Hopkin 1997) and provide an early indication of environmental disturbance (Abbas 2012). The size of microarthropod population and activity of its members can be modified by numerous factors, such as temperature, moisture content (Pflug and Wolters 2001, Palacios-Vargas et al 2007, Xu et al. 2012), altitude (Illig et al. 2010), compaction (Lee et al. 2009; Lindo and Visser 2003, 2004), and

different silvicultural practices (Moore et al. 1984; Lindo and Visser 2003, 2004; Wickings and Grandy 2013) to name a few. Soil fertility determines forest vegetation diversity and thus litter's quality, which in turn attributes to microarthropod community structure (Ferguson and Berube 2004, Ayres et al. 2006, Sylvain and Buddle 2010). Some researches suggest that forest habitat may influence forest floor invertebrate community to ensure rapid decomposition of its litter (Ferguson 2001, Wardle et al. 2004). Wardle et al (2004) showed the relationship of aboveground and belowground components of terrestrial ecosystems and their close interlinkage at community level, reinforced by a greater degree of specificity between plants and soil organisms.

The present study examined litter microarthropod communities, specifically their absolute and relative densities, in pine forests in Zhytomyr Polissya, Ukraine. Different site conditions and different age of stands were examined to test the hypothesis that these factors affect the abundance and composition of litter communities. We predicted that (1) litter in each successional forest age group would be more microarthropod abundant; (2) site conditions would alter the absolute microarthropod density within a particular age group; and (3) community composition would differ along forest age gradient.

Material and Methods

Description of study areas

This study was conducted at the Lugyny State Forest Enterprise of Zhytomyr Polissya zone. The area is located at the latitude of 51°04'52" north and the longitude of 28°24'07" east within the altitude of 156 m above sea level in the Northern part of Ukraine. The climate at this area is mild continental with warm summer and a mean daily temperature in July +20.7 °C and mild winter with a mean temperature in January –2.7 °C. Total annual precipitation in 2011 was 368.6 mm (Meteo 2011). The level of ground water is 2.5–3.5 m.

Studies were carried out in two forest site conditions, which according to the forest typology adopted in Ukraine, correspond to A2 and B2 types (classification by Pogrebnyak 1955). The classification of sites is based on two main components, soil type and vegetation. A2 type is a mesophilic (slight moist) pine forest, growing on poor sandy sod-podzolic soil. The major tree species is *Pinus sylvestris* L. with limited quantity of Pedunculate oak (*Quercus robur* L.), Silver birch (*Betula pendula* Roth), or Common aspen (*Populus tremula* L.). The understory vegetation is represented mostly by herbaceous species such as mosses, *Pyrola umbellata* L., *Rubus saxatilis* L., *Chamaecytisus ruthenicus* (Fisch. ex Wol.) Klásk. and some shrub species like *Vaccinium vitis-idaea* L. and *Calluna vulgaris* (L.) Hull.

B2 site is a mesophilic Pinetum compositum, growing on relatively poor sandy soil with layers of clay. Forest stands are usually two-storey, with the upper storey formed by pines with limited amount of birch and lower storey represented by oaks and/or aspen. The undergrowth is represented by *Rhamnus frangula* L., *Sorbus aucuparia* L. Herbaceous cover consists of *Fragaria vesca* L., *Convallaria majalis* L., *Pteridium aquilinum* Kuhn, *Vaccinium myrtillus* L., *Vaccinium vitis-idaea* and *Calluna vulgaris*.

The following age groups of forest stands were investigated in each type of site conditions (the abbreviations are given in brackets): cut (Ct); non-closed (NC), young (Yg), middle-aged (MA), and mature (Mt). In A2 forest, in the cut site the harvesting occurred in December 2009 at the age of 55 years; trees were infected by fungal disease (*Heterobasidion annosum* (Fr.) Bref.). The age of non-closed stand was 4 years, young – 23, middle-aged – 43, and mature – 90 years. In B2 forest type, in the cut site the sanitation cutting of 70-year-old trees occurred in 2010; the age of non-closed stand was 4 years, young – 30, middle-aged – 56, and mature – 92 years.

Sampling

Sampling was performed at the beginning of April, August, and November 2011. A sample was a square litter monolith sized 10×10 cm each (100 cm^2) with the thickness of a monolith equaled the thickness of the litter (Table 1). A total of 150 samples were examined: 2 forest types × 5 age groups × 3 seasons × 5 sampling occasions. Microarthropod extraction was conducted using modified Tullgren funnels (diameter 15 cm) containing inserted wire mesh with cells 2×2 mm. An electrical bulb was used as a source of heat. Invertebrates dropped through the exit hole of the funnel into collecting bottles containing 70 % alcohol. Extraction time lasted two days. The total numbers of individuals in major groups were calculated with dissecting microscope at 40x magnification. Acari were identified to suborders Prostigmata, Mesostigmata, Oribatida, and Astigmata.

The analysis of the absolute and relative density of all microarthropods as well as their main groups depending on the age of stands and type of site conditions has been employed. The absolute density was expressed as the number of individuals per square meter (ind·m^{-2}). As the thickness of a litter layer differed in each particular site, to eliminate its effect on the absolute microarthropod density while comparing sites with different litter quantity, the calculated number of animals in each sample was divided by its litter thickness. The relative abundance (percentage of total) of microarthropod suborders was calculated using the formula (1):

$$RA = \frac{Nis}{N} \cdot 100\ ,\ \% \qquad (1),$$

where: *RA* – relative abundance of microarthropod suborders; *Nis* – number of individuals in a suborder; *N* – total number of microarthropods.

Table 1. Mean thickness of litter in sampling areas, cm.

Site condition	Cut	Non-closed	Young	Middle-aged	Mature
A2	1.5	1.0	3.0	3.5	4.0
B2	0.5	0.5	2.0	3.0	3.5

Statistical analysis

Since the distribution of data was not normal even after log-transformation, non-parametric tests, Mann-Whitney (for comparison of two samples) and Kruskal-Wallis (for analysis of variances), were applied for statistical analysis. Hierarchical

cluster analysis was used to group the most similar age groups of stands within a particular type of forest site conditions on the basis of absolute density of litter microarthropods. All calculations were done in XLSTAT-Pro 2013.4.07.

Results

In stands of all studied age groups, except the young, the mean absolute density of total microarthropods was significantly higher in B2 sites than in A2 (Mann-Whitney test, $P<0.05$) (Figure. 1,

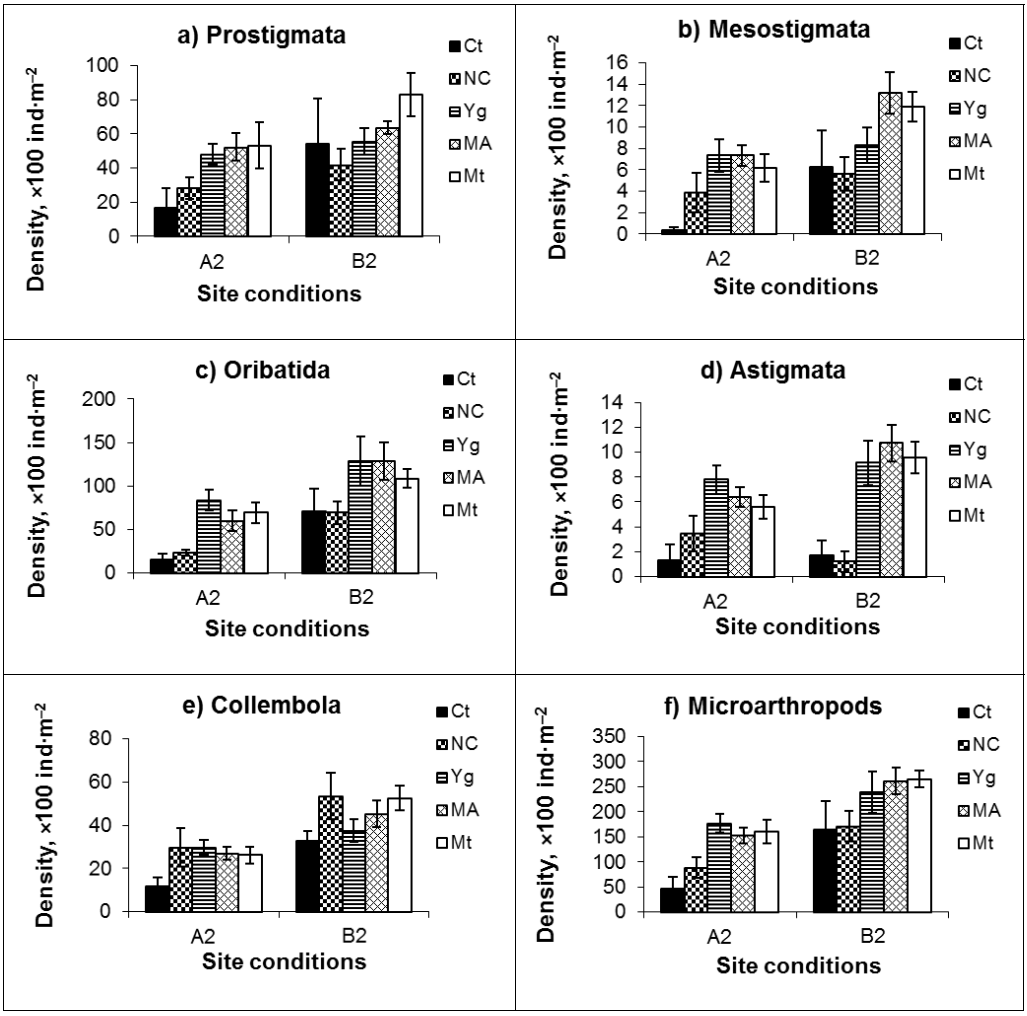

Fig. 1. Absolute density of (a) Prostigmata, (b) Mesostigmata, (c) Oribatida, (d) Astigmata, (e) Collembola, and (f) Total microarthropods in litters of cut, non-closed, young, middle-aged and mature stands in A2 and B2 forest site conditions.

Note: Values are means ± SE. Ct – cut, NC – non-closed, Yg – young, MA – middle-aged, Mt – mature stand.

Table 2). The absolute density of mite taxa and collembolans was also higher in the litter of B2 site type (Figure 1). Significant differences for mite density were observed in cut, middle-aged, and mature stands and for collembolan density – in non-closed, middle-aged, and mature stands (Table 2).

Within each type of site conditions, litter microarthropod density fluctuated depending on the stand age. In A2 site condition, the lowest densities of all studied microarthropod groups were observed in cut forest (Figure 1). There were no significant differences observed between cut and non-closed stands as well as young and older stands (Table 3). The numbers of mites, Collembola and all microarthropods were significantly higher in young and older stands compared to cuts.

Within B2 site conditions, the dynamic trends in microarthropod densities in most cases were similar to those in A2. The lowest mean absolute densities of mite taxa were observed in non-closed stands followed by cut site (Figure 1). The minimal absolute density of collembolans was observed in the litter of cut forest, whereas the maximal – in non-closed stands; however, it was not statistically significant (Table 3). The differences in microarthropod densities in stands of adjacent age groups were not significant for all taxa except Astigmata, which density in the young stand was significantly higher than in the cut and non-closed stand (Table 3). Differences in absolute densities for most microarthropod taxa were statistically significant only between stands of distant age groups: between cut and middle-aged or mature stands (Table. 3).

Table 2. The results of comparison of absolute litter microarthropod densities between A2 and B2 forest site conditions (Mann-Whitney test, α=0.05)

Microarthropods	Age groups of stands				
	Cut	Non-closed	Young	Middle-aged	Mature
Prostigmata					
U	58.00	91.00	99.00	88.50	56.00
P	0.024	0.383	0.59	0.33	0.02
Mesostigmata					
U	68.00	89.00	104.50	49.50	47.00
P	0.024	0.307	0.755	0.01	0.007
Oribatida					
U	31.50	43.50	95.50	47.00	57.00
P	0.001	0.004	0.494	0.007	0.023
Astigmata					
U	106.00	140.50	104.50	64.50	55.00
P	0.633	0.143	0.740	0.049	0.018
Collembola					
U	92.50	58.50	94.00	54.50	42.00
P	0.417	0.026	0.455	0.017	0.004
All microarthropods					
U	24.50	60.50	98.00	41.00	40.00
P	0.0003	0.033	0.0561	0.003	0.003

Note: U – sum of ranks, P – probability.

Table 3. The results of comparison of absolute litter microarthropod densities in stands of different ages for A2 and B2 forest site conditions (Kruskal-Wallis test, multiple pairwise comparison, α=0.05, Bonferroni corrected significance level: 0.005)

Microarthropods	Age groups of stands					*P*
	Cut	Non-closed	Young	Middle-aged	Mature	
A2						
Prostigmata	A	AB	B	B	B	<0.0001
Mesostigmata	A	AB	BC	C	BC	<0.005
Oribatida	A	AB	C	BC	BC	<0.001
Astigmata	A	AB	C	BC	BC	<0.005
Collembola	A	AB	B	B	B	<0.005
All microarthropods	A	AB	B	B	B	<0.0001
B2						
Prostigmata	A	AB	AB	B	B	≤0.001
Mesostigmata	A	AB	AB	B	B	<0.0001
Oribatida	A	AB	AB	B	B	<0.005
Astigmata	A	A	B	B	B	≤0.001
Collembola	A	AB	AB	AB	B	<0.005
All microarthropods	A	AB	AB	B	B	≤ 0.001

Note: Within each row, different letters are significantly different.

Hierarchical cluster analysis (Figure 2) showed that patterns of absolute microarthropod density in A2 site conditions were similar between the middle-aged and mature stands whereas microarthropod densities in young stands were more similar to those in the non-closed stands. In B2 site conditions, absolute densities of microarthropods were similar in young and middle-aged stands followed by non-closed stand and

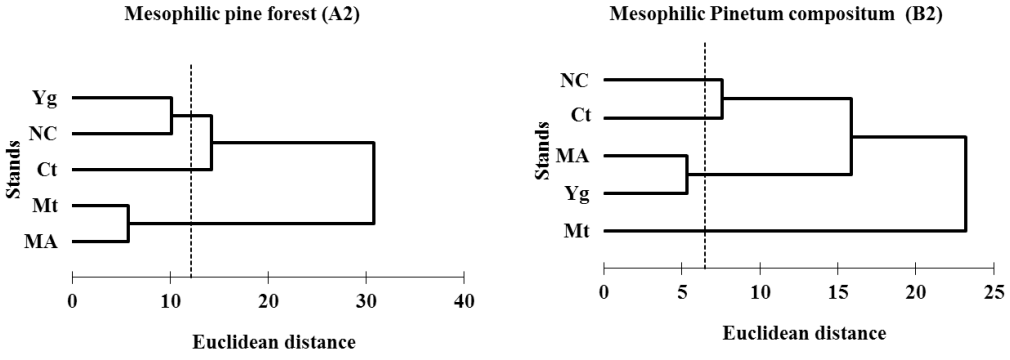

Fig. 2. Agglomerative hierarchical cluster analysis of forest age groups based on absolute abundance of forest litter microarthropods for A2 and B2 site conditions.

Note: Groups connected at lower distance index are more similar, than those with higher distance indices.

Table 4. Relative densities of main suborders of litter microarthropods in stands of different ages for A2 and B2 forest site conditions.

Microarthropods	Cut	Non-closed	Young	Middle-aged	Mature
A2					
Prostigmata	25.14 (5.74)^{a}	30.42 (3.47)^{a}	28.92 (3.00)^{a}	35.50 (5.03)^{a}	31.01 (4.96)^{a}
Mesostigmata	1.56 (1.29)^{a}	4.23 (1.49)^{ab}	4.03 (0.49)^{b}	5.30 (0.87)^{b}	3.60 (0.39)^{b}
Oribatida	40.16 (4.84)^{a}	33.37 (2.88)^{a}	44.76 (3.98)^{a}	36.69 (4.51)^{a}	43.38 (4.22)^{a}
Astigmata	0.35 (0.35)^{a}	2.63 (0.99)^{ab}	4.68 (0.74)^{b}	4.52 (0.57)^{b}	3.45 (0.26)^{b}
Collembola	32.79 (4.83)^{ab}	29.35 (1.58)^{b}	17.62 (1.58)^{a}	17.99 (1.19)^{ab}	18.55 (2.35)^{a}
B2					
Prostigmata	24.83 (4.44)^{a}	22.54 (4.25)^{a}	27.31 (3.28)^{a}	28.42 (3.31)^{a}	30.00 (3.55)^{a}
Mesostigmata	2.70 (0.95)^{a}	2.41 (0.80)^{a}	3.49 (0.52)^{ab}	5.23 (0.54)^{b}	4.37 (0.44)^{ab}
Oribatida	38.76 (3.68)^{a}	42.28 (3.80)^{a}	47.45 (4.00)^{a}	45.18 (3.56)^{a}	41.76 (3.92)^{a}
Astigmata	0.50 (0.39)^{a}	0.53 (0.40)^{a}	3.61 (0.47)^{b}	4.11 (0.42)^{b}	3.62 (0.44)^{b}
Collembola	33.21 (4.59)^{b}	32.24 (3.34)^{b}	18.14 (1.70)^{a}	17.06 (1.19)^{a}	20.25 (2.27)^{ab}

Note: Values are means, with SE given in parenthesis. Within each row, values followed by a different letter are significantly different, based on Kruskal-Wallis test (multiple pairwise comparison, α=0.05, Bonferroni corrected significance level: 0.005).

cuts. The mature stand was dissimilar to any other age group in B2 site conditions.

The relative density of prostigmatid and oribatid mites in litter samples form A2 sites fluctuated insignificantly in stands of different ages (Table 4). Mesostigmatid and astigmatid mite densities in samples from young and older stands were significantly higher than those from cut site (Table 4). Collembola content was the highest in litter from cut forest and decreased with forest age reaching its minimum in young stand. In older forests, it remained almost the same. Significant differences in collembolan relative densities were noted in litters of young and mature stands compared to non-closed one (Table 4). Similar trend was observed in B2 site conditions. Significant differences were also noted for mesostigmatids, astigmatids, and collembolans in cut or non-closed stands versus any other age group (Table 4).

Discussion

The main hypothesis tested in this study was whether the type of forest site conditions influences the density and structure of litter microarthropod community. We sampled litter in forests areas, which, according to Pohrebnyak classification currently used for forest typology in Ukraine, belong to types A2 and B2. Although both of them have similar soil moisture conditions (both are mesophilic soils), they differ on soil fertility, which is higher in B2 conditions. Soil fertility determines forest

vegetation diversity and thus litter's quality, which in turn attributes to the microarthropod community structure (Ferguson and Berube 2004, Ayres et al. 2006). According to Sylvain and Buddle (2010), more diverse aboveground plant assemblages support more diverse mite assemblage. In our studies, absolute density of all litter microarthropods and their main taxa was higher in forest areas of B2 conditions (Figure 1) in stands of all age groups and this supports our prediction. However, significant difference was observed mostly in cut, middle-aged, and mature stands (Table 2).

The lowest absolute abundance of microarthropods was observed in litter from cut forest sites. The reduction in microarthropod numbers in cut forests compared to young and older age groups probably occurred due to forest floor disturbance following forest harvesting. Harvesting is always associated with soil compaction, which increases soil bulk density and decreases soil porosity, aeration, and infiltration capacity (Greacen and Sands 1980; Huang et al. 1996, Kozlowski 1999). Lindo and Visner (2003) observed a significant negative relationship between microarthropod abundance and soil bulk density associated with harvesting. Tan and Chang (2007) studied the effect of soil compaction and forest litter amendment on microbial properties and processes in this boreal forest soil under controlled conditions and concluded that forest management practices that alter soil porosity (through compaction) and organic matter distribution in the soil profile can dramatically change soil C and N dynamics that may result in the eventual change in soil C and N concentrations or availability. Compaction can shift soil conditions towards anaerobic state that is associated with reduced aerobic microbial activities, increased denitrification rates, and reduced uptake of nutrients resulting in decrease of woody plants growth and yields of harvestable plant products (Greacen and Sands 1980, Kozlowski 1999). Litter quantity is another important factor influencing the abundance of forest floor microarthopods. The decrease in litter input leads to the reduction of organic matter available for decomposition. In present study, the drop in absolute microarthropod density and changes in litter microarthropod community structure in cut sites and non-closed stands relative to older-aged stands may probably be explained by some of above mentioned factors.

Community structure studies showed an increase in relative content of mesostigmatid and astigmatid mites and decrease in Collembola content in litters of middle-aged and mature stands relative to cuts in both studied site conditions. Fluctuations of relative densities of oribatid and prostigmatid mites along the forest age gradient were not significant. In contrast, Lindo and Visner (2004) reported a reduced relative abundance of prostigmatid and oribatid mites and increased relative abundance of mesostigmatid mites in forest floor cores from clear-cut and corridor treatments as a result of physical disturbance of the forest floor. In our studies, there were no differences in litter community compositions between cut site and non-closed stands as well as between young and older age stands.

Conclusions

Mean absolute density of total litter microarthropods and their main suborders

in sites with mesofilic Pinetum compositum (B2) was higher than in mesofilic pine forest (A2). Within each type of site conditions, litter microarthropod density fluctuated depending on the forest age; however, the differences in absolute densities for most microarthropod taxa were statistically significant only between stands of distant age groups: between cut and middle-aged or mature stands. Decreased absolute density of total litter microarthopods, Acari suborders and Collembola in cut sites and non-closed stands may be the result of forest floor compaction associated with harvesting.

Litter microarthropod community structure differed along forest age gradient. The relative densities of mesostigmatid and astigmatid mites increased, whereas Collembola content decreased. The differences were significant in middle-aged and mature stands relative to cut sites.

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ANALYSIS OF THE FOREST SEED PRODUCTION BASE OF *ACER PLATANOIDES* L. IN BULGARIA

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Abstract

The research considers all Norway maple seed sources included in the National Register of Forestry Seed Production Base in Bulgaria. Also, all forest stands and plantations where Norway maple shares more than 50 % of the composition were selected from the National Data Base of Forest Territories in Bulgaria. The age, mean height and diameter at breast height (DBH) were determined. For the plantations, where the initial planting design was known, the percentage of survival was calculated. For estimation of growing indicators, Tables for High Beech Stands were used, according to the accepted Equivalency List of Tables for Tree Species and Used Abbreviations. The site index, height rates, density (DS), basal area (G_{ba}) and volume (V) per 1 ha, mean annual diameter increment (Z_d) and mean annual height increment (Z_h) were calculated. The selection category of the stands was defined according to the height, in the tables for growth and productivity for High-stemmed beech stands, I-st site index. For determining the selection structure of the stands, the categorization of trees, accepted in the method for analysis of forest plantations was used. The altitude of the forest stands, where the Norway maple predominates, varies from 100 to 1000 m with mean value of 400 m. Both natural stands and plantations are located in habitats, categorized as moderately-rich to rich. The moisture level of the soils is relatively good – from fresh to humid. The terrain expositions of the stands are heterogeneous i.e. 61 % of them are located on shady and 39 % on sunny expositions. The analysis of silvicultural and dendrometric characteristics of the investigated objects shows that Norway maple could have predominantly participation in both forest plantations and natural forest stands. The intensive height growth of the species was registered in both the sub-belt of plane-hills Oak forests and the sub-belt of low-mountain forests of Sessile oak, Common beech and Common fir. This fact shows its pliability to the habitats within the altitudes from 150 to 900 m. The mean diameter at 1.3 m, in the 44–54 years old stands varies from 18 cm to 30 cm. In the category “absolute plus” fall the stands in SFS Berkovica, Vidin, Byala and Gurkovo. However, the results show that the number of stands valuable from the breeding point of view with predominant participation of *Acer platanoides*, is limited, especially in South Bulgaria. Meanwhile, the presence of valuable phenotypes requires their conservation and wider use for production of seedlings for forestry and urban planting.

Key words: distribution, growth, Norway maple, plantations, seed sources, selection, stands.

Introduction

Providing sowing materials with good, proved genetic and germination qualities is a main scientific and practical aim in the production of the forest (Milev et al. 1999) and ornamental plants (Aleksandrov 2007).

Nowadays in Bulgaria there is a constantly growing interest in broadleaves, either for forest planting (EFA 2012), or for the purposes of landscaping. The role of the native species is more and more valued, considering biodiversity conservation (MAF 2011, EFA 2011) and the fact that about one-third of the country's territory is included within the framework of NATURA 2000.

In Bulgaria there are still unused opportunities in investigating and using of species of genus *Acer* for the above mentioned purposes. Norway maple is considered as one of the most valued representative of the genus from forestry point of view (Pandeva 2004) and is reported to show good adaptive behavior in urban environment (Dirr 1998). It tolerates wide range of soils, from sandy to clay and from acidic to alkaline soils (Dirr 1998), but could not bear dry and damp growth conditions (Suszka et al. 1996). It endures air pollution, particularly ozone and sulfur dioxide (Dirr 1998). Also, it is popular with its diversity of ornamental cultivars (Artushenko et al. 1958, Santamour 1976, Krüssmann G. 1984, Dirr 1998, Coombes 1992, Zasada and Strong 2008).

Acer platanoides distribution includes almost the whole Europe, Caucasus, Turkey and Iran. North it spreads to Norway and Finland. In South Europe it reaches altitude of 1000 m and rarely 1200 m. Norway maple has scattered distribution and does not form pure stands, but takes part in groups, in the mixed broadleaved forests (Artushenko et al. 1958, Pandeva 2004, Schmucker 1942, Krüssmann 1984). In Bulgaria it spreads at altitude from 500 to 1500 m, almost in the whole country, apart from Pirin and Slavyanka mountains (Assyov et al. 2012, Milev et al. 2004, Pandeva 2004). Wide distribution is suggesting that different populations are not genetically homogenous. Despite of that, its seed production resources in the country are briefly investigated.

The aim of this study is to propose suggestions for updating the Norway maple forestry seed production data base in Bulgaria by analyzing the condition of the Norway maple stands included in the National forestry seed production register and by searching for additional stands with good qualities.

Objects

The research includes all Norway maple seed sources listed in the National Register of Forestry Seed Production Base in Bulgaria (NSFSPBB, Tables 1 and 6).

All forest stands in which Norway maple presents more than half of the composition were selected from the National Data Base of Forestry Territories in Bulgaria (NDBFTB, EFA 2012). These are 29 stands spread in 12 State forestry services (SFS). Furthermore are selected those ones, which are in good phytosanitary condition and are older than 20 years (Tables 2 and 6). The stands in SFS General Toshevo, which are field protection forestry belts, are removed from the preliminary list by terrain assessment.

A forest stand in SFS Gurkovo, which does not belong to either of the above mentioned registers was identified in the process of field work and was added to the study.

Methods of Study

The information about conditions of the habitats in the investigated Norway maple stands was taken from the forest management plans of the respective SFS.

Table 1. Habitat conditions of the seed production stands taken from the National forestry seed production register.

State forestry service	Forest stand	Area, ha	Altitude, m	Exposition	Slope, degrees	Habitat Site type	Relief form	Soil type	Soil texture	Soil stoniness	Soil density	Basal rock	Soil richness
Botevgrad	246d	15.1	900	N	27	M-NBG-II-1/ C_2(30)	Slope upper part	Eutric Cambisols	Moderete loam	Slightly stony	Optimum	Quartzite	Medium
Balchik	39m (part)	0.5	150	–	0	M-DCH-I-2/ D_1(12)	Flat	Haplic Kastanozems	Moderete loam	Slightly stony	Compacted	Loess	High
Kotel	3p	4.1	900	N	32	T-ESP-II-1/ C_2(71)	Slope upper part	Eutric Cambisols	Loamy sand	Stony	Optimum	Limestone marl	Medium
Tzonevo	80a	15.8	350	NW	17	T-ESP-I-2/ $СД_{23}$(60)	Slope lower part	Grey Luvisols	Moderete loam	Slightly stony	Optimum	Quartz sandstone	Medium to high
Borima	92s	5.6	650	NW	22	M-NBG-II-1/ C_2(27)	Slope upper part	Grey Luvisols	Moderete loam	Slightly stony	Compacted	Limestone marl	Medium
Aitos	160b	17.7	350	W	22	T-ESP-I-2/ C_{12}(56)	Slope lower part	Haplic Chromic Luvisols	Moderete loam	Slightly stony	Compacted	–	Medium
Byala	39g	23.7	300	NW	12	M-NBG-I-2/ C_2(14)	Slope upper part	Carbonic Kastanozems	Moderete loam	Stony	Compacted	Limestone	Medium to high
Tran	148g	21.4	1100	E	27	M-KI-II-2/ C_2(36)	Slope upper part	Eutric Cambisols	Loamy sand	Stony	Optimum	Sandstone	Medium
Smyadovo	11d	20.7	450	NE	19	T-ESP-I-2/ $CD_{2,3}$(60)	Slope upper part	Grey Luvisols	Moderete loam	Slightly stony	Optimum	Sandstone	Medium to high

The code characterizing the site type is haccording to the requirements of The Classification Scheme for the Types of Forest Habitats in Bulgaria (CSTFHB) (Executive Forestry Agency 2011).

The age of stands is taken from the current management plans of the SFSs and updated in the process of our investigation.

Diameters at breast height (DBH) of all trees within the stands less than 5 dka, were measured with 1 cm accuracy. In the larger stands we established temporary experimental plots of 1.5 dka. For the plantations, where the initial planting design is known, survival rate was calculated. The mean diameter was calculated according to the mean basal area. The mean height was calculated from the height of three trees, one with a mean diameter and two with the next closest diameters above and below the mean value.

For estimation of growing indicators, Tables for High-stemmed Beech Stands were used, according to the accepted by Krastanov and Raykov (2004), Equivalency List of Tables for Tree Species and Used Abbreviations.

The site index was defined according to the Tables for High Beech Stands (Nedyalkov 1960). For the height rates the tables of Duhovnikov (1963) were used. The density (DS), basal area (G_{ba}) and volume (V) per 1 ha, mean annual diameter increment (Z_d) and mean annual height increment (Z_h) were calculated. The volume was calculated according to the Volume and Assortment Tables for High-stemmed Beech Stands by Duhovnikov (1963), and the density – ac-

cording to volume of the stands with the Tables for Growth and Productivity (Nedyalkov 1960).

The selection category of the stands was defined according to the height, in the tables for growth and productivity for high-stemmed beech stands, I-st site index (Nedyalkov 1960).

For determining the quality structure of the stands, the category scale of trees, described in the method for analysis of forest plantations was used (Milev 2013).

Results and Discussion

Stands, from the date base of the National Forestry Agency, subject of assessment

According to the data from Executive Forest Agency (EFA), the number of forestry stands where Norway maple represents 50 % or more of the stand composition, is 29. Twenty-one of them are located in Northern Bulgaria (Fig. 1, Table 6), and are spread on the territory of 10 SFS. The other 8 are located in Southern Bulgaria and are on the territory of SFS Gurkovo and Haskovo. The ratio of natural forest stands to plantations is 15/14 (Fig. 1). The plantations were established at the territory of the following SFSs: Silistra, Kipilovo, Byala, Vratza, Haskovo and General Toshevo. The altitude of the forest stands, where the Norway maple predominates, varies from 100 to 1000 m with mean value of 400 m.

Both natural stands and plantations are located in habitats, categorized as mid-rich to rich. The moisture level of the soils is relatively good – from fresh to humid. The terrain expositions of the stands are heterogeneous i.e. they are located on shady (18), as well as sunny (11) expositions (Tables 1 and 2).

Registered stands for seed production

Norway maple stands, registered for seed production, are located at altitude between 150 and 1100 m on total area of 155.5 ha. The results of the terrain investigation

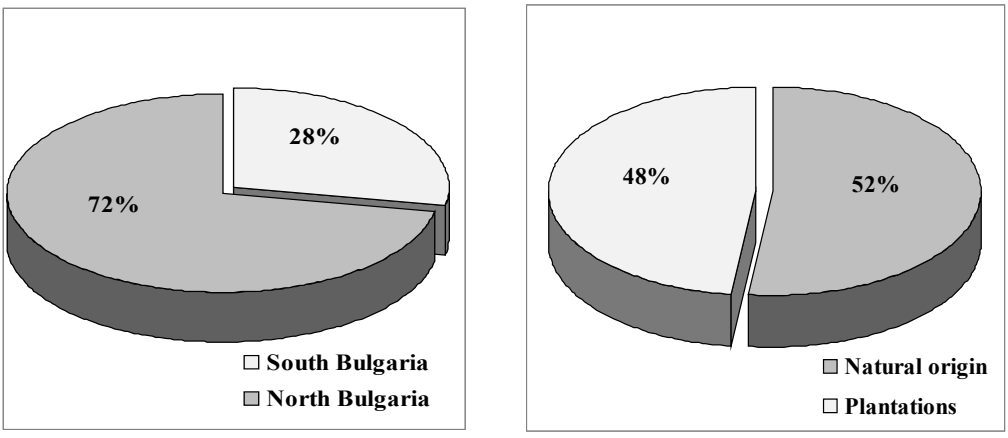

Fig. 1. Distribution of the forest stands with predominant participation of Norway maple by origin and geographic location.

showed that most of them do not posses the necessary characteristics to be used as source of reproduction material.

The stand in SFS Botevgrad was damaged by ice in 2007 and after sanitary felling in 2009 and 2010 Norway maple was removed and does not exist anymore.

In SFS Borima the participation of the species is presented by 19 individuals. Most of them are characterized by forked stems and for this reason are not good as breeding material.

Similar process of transformation in the composition of stands, with dropping out of Norway maple was registered in SFSs Kotel, Tzonevo, Tran and Aitos, and only single trees were ascertained. With age from 130 to 165 years in these forest stands (Table 1), Norway maple drops out of the composition and is being replaced by species with higher longevity like Common beech and Pedunculate oak.

In the stands at SFS Byala and SFS Smyadovo, Norway maple is also presented only by single trees, and it is not mentioned at all in the management plans.

These facts show that only the plantation in SFS Balchik could be a subject of interest from tree breeding and seed production point of view.

Observations in all experimental stands showed that in the natural mixed forest, Norway maple grows mostly with Sycamore (*Acer pseudoplatanus* L.), Common ash (*Fraxinus excelsior* L.), Common beech (*Fagus sylvatica* L.) and Turkish hazel (*Corylus colurna* L.) (Table 3).

The plantations have been established mostly in the lower forest belt, in the subbelt of Oak and mixed deciduous forests (Tables 1, 2, and 6). The planting design varies substantially, from 1×1 m (SFS Balchik) to 4×4 m (SFS Byala) (Table 3).

The survival of Norway maple in the studied plantations is 10–11 % at the age of 50 (SFS Byala and SFS Balchik) (Table 3).

The analysis of silvicultural and dendrometric characteristics of the investigated stands shows that Norway maple could have predominant participation in both forest plantations (SFS Balchik) and natural forest stands (SFS Vidin) (Table 3). According to the NDBFTB the participation of *Acer platanoides* in stand 30 g (SFS Gurkovo) is limited to single trees. In reality though, in the territory of 23.8 ha there is an area of 0.6 ha, in which the participation of Norway maple is 60 % of the composition and it must be taken in to consideration, because of the limited stands with predominant participation of the species.

The height of *Acer platanoides* at age from 44 to 54 years varies from 18.5 m (SFS Balchik) to 27 m (SFS Berkovitza) and at the age of 120 years it reaches 30.5 m (SFS Gurkovo), which is considered as the limit height of the species (Milev et al. 2004, Suszka et al. 1996). The stands in SFS Berkovitza are an example showing the possibility of Norway maple to reach the maximum height at age around 50 years. According to the registered heights, all stands can be classified in the 1st site index category (Table 3).

The comparison between the measured heights and the heights in the tables for growth and productivity of Common beech for the respective age reveals that mean height of the stands in SFS Berkovitza and SFS Vidin are higher than the ones in the table while opposite trend was found in SFS Balchik and SFS Byala. Our investigations indicate that the habitats in the middle forest belt are better for Nor-

Table 2. Habitat conditions of the investigated stands, chosen from the data base of the National Forestry agency.

State forestry service	Forest stand	Area, ha	Altitude, m	Exposition	Slope, degrees	Habitat Site type	Relief form	Soil type	Soil texture	Soil stoniness	Soil density	Basal rock	Soil richness
Berkovitza	204 sh_2	0.3	700	W	12	M-NBG-II-1/ $CD_{2,3}$ (29)	Slope upper part	Eutric Cambisols	Loamy sand	Slightly stony	Optimum	Granite	Medium to high
Vidin	390b, 391b	33	870	NE, SE	16	M-NBG-II-1/ C_2(30)	Slope upper part	Eutric Cambisols	Loamy sand	Slightly stony	Optimum	Diabase	Medium
Byala	243v	1.9	250	N	3	M-NBG-I-2/ D_2(12)	Flat	Grey Luvisols, Mollic	Moderete loam	Slightly stony	Compacted	Limestone	High
Gurkovo	30g (part)	0.6	900	E	29	T-GT-II-1/C_2(71)	Slope upper part	Eutric Cambisols	Moderete loam	Slightly stony	Optimum	Marl	Medium

Table 3. Silvicultural and dendrometric characteristics of the investigated stands.

State forestry service	Forest stand	Origin	Participation ratio	Structure	Scheme, m/m	Number of trees, ha^{-1}	Survival, %	Age, years	H, m	$D_{1.3}$, cm	Site index of *Ap*	Basal area of *Ap*, m^2/ha	Basal area of all species, m^2/ha	Mean height increment of *Ap*, cm/yr	Mean diameter increment of *Ap*, cm/yr	Mean volume increment, m^3/ha.yr	Volume of *Ap*, m^3/ha	Volume of all species, m^3/ha	Stand density
Berkovitza	204 sh_2	Natural	*Ap*3, *Aps*6, *Fs*1	uneven	–	473		54	27	25	I	7.15	23.6	50	0.45	5.03	83	272	0.59
Vidin	390b, 391b	Natural	*Ap*5, *Fe*2, *Fs*2, *Aps*1	uneven	–	410		44	20	19	I	5.94	12	45	0.43	2.58	56	113.5	0.33
Balchik	39m (part)	Plantation	*Ap*10	even	1/1	1100	11	50	18.5	18	I	26.8	26.8	37	0.36	4.66	233	233	0.5
Byala	243v	Plantation	*Fe*6, *Ap*4	even	4/4	62	10	50	19	30	I	1.6	5.1	38	0.60	0.94	13	46.8	0.1
Gurkovo	30g (part)	Natural	*Ap*6, *Aps*2, *Cc*2, *Fs*	uneven	-	247		120	30.5	46	I	24.5	40.7	25	0.38	4.58	333	549	0.6

Note: *Ap* – *Acer platanoides*, *Aps* – *Acer pseudoplatanus*, *Fs* – *Fagus sylvatica*, *Fe* – *Fraxinus excelsior*, *Cc* – *Corylus colurna*.

way maple than the habitats in the lower forest belt.

Fast height growth of the species was registered in both the sub-belt of plane-hills Oak forests and the sub-belt of low-mountain forests of Sessile oak, Common beech and Silver fir. This fact shows its tolerance to the habitats within the altitudinal range from 150 to 900 m. No light dependence was detected, and the growth intensity was related mostly to the soil richness and moisture. Our results concord to the opinion of Dirr (1998) and Suszka et al. (1996) for the wide range of ecological pliability of the species to the soil conditions.

Mean annual height increment of the investigated stands varies from 37 cm (SFS Balchik) to 50 cm (SFS Berkovitza) and in 120 years of age it decreases to 25 cm (SFS Gurkovo), which is explained by reaching the limits of life span of the species (Table 3).

Mean diameter in the 44–54 years old stands varies from 18 cm (SFS Balchik) to 30 cm (SFS Byala), and at the age of 120 years it is 46 cm (SFS Gurkovo) (Table 3).

Mean annual diameter increment in all stands is higher than the values in the growth and productivity tables. Since diameter growth is a function of growing space, i.e. stand density, it is important to note that in all the investigated stands the density is by far less than the value in the growth and productivity tables. It means that Norway maple stands cannot grow at high density typical for Common beech. Mean annual diameter increment varies from 0.36 (SFS Balchik) to 0.60 cm (SFS Byala) (Table 3).

The volume in the 1st site index stands varies from 113.5 (SFS Vidin) to 272 $m^3 \cdot ha^{-1}$ (SFS Berkovitza), with annual volume growth from 2.58 to 5.03 $m^3 \cdot ha^{-1}$. The plantation in SFS Byala is excluded because of the very low density, which makes it not typical forest stand. All the objects show that in age around 50 years the volume is still strongly affected by the stand density (Table 3). At the stage of maturity (SFS Gurkovo) the volume is 549 $m^3 \cdot ha^{-1}$, and mean annual volume increment is 4.58 $m^3 \cdot ha^{-1}$ (Table 3).

The analysis of phenotypic structure shows that the stands in SFS Berkovitza, Vidin and Byala could be classified in “plus” category for height, while those in Balchik and Gurkovo – in “normal” category. “Normal” in diameter is the stand in SFS Balchik and all other falls in the category “plus stands”. The stands in SFS Berkovica, Vidin, Byala, and Gurkovo can be classified in the category “absolute plus” (Table 4).

There are enough high-quality individuals in all stands, their share ranging from 56 % (SFS Byala) to 82 % (SFS Balchik) (Table 4).

After updating of the register the stands in SFS Balchik, stand 39m, must be kept (Fig. 2, Table 6). From the NS-FSPBB should be exclude the stands in SFS Botevgrad, stand 246d; Kotel, stand 3p; Tzonevo, stand 80a; Borima, stand 92c; and Aitos, stand 160b; Byala, stand 39g; Smyadovo, stand 11g; Tran, stand 148g (Fig. 2, Table 6).

Conclusions

The stands in which Norway maple participation is limited to single trees are not suitable for reproduction, because there are preconditions for self-pollination and homozygous offspring, from which the

Table 4. Breeding category and phenotypic structure of the investigated stands.

State forestry service	Forest stand	Category			Phenotypic quality structure						
					Good phenotypic quality, %	Non good phenotypic quality, %					
		by H	by D	Absolutely +		Sum	Y	V	S	OS	Damaged
Berkovitza	204 sh_2	+	+	yes	72	28	16	7	5	0	0
Vidin	390b, 391b	+	+	yes	71	25	7	3	7	8	4
Balchik	39m (part)	normal	normal	no	82	18	6	0	5	2	5
Byala	243v	+	+	yes	56	44	9	23	7	0	5
Gurkovo	30g (part)	normal	+	yes	71	29	19	5	5	0	0

Note: Y– forked stem, V – twin stem, S – crooked stem, OS – obliquely stem.

sowing qualities of seeds could be lowered. Further, inbreeding decreases the biodiversity within the species and the possibility for lower adaptive capacity and growing characteristics of the offspring appears.

Fig. 2. Location map of the investigated Norway maple stands.

Table 5. Young Norway maple stands, interest of a future investigations.

State forestry service	Forest stand	Area, ha	Altitude, m	Exposition	Slope gradient, degrees	Habitat Site type	Relief form	Soil type	Soil texture	Soil stoniness	Soil density	Basal rock	Soil richness
Kipilovo	144b	0.6	600	E	18	M-NBG-II-1/ C_2(30)	Slope lower part	Eutric Cambisols	Loamy sand	Stony	Optimum	Sandstone	Medium
Gurkovo	56v	0.4	800	SW	13	T-GT-II-1/ C_2(71)	Slope upper part	Eutric Cambisols	Loamy sand	Slightly stony	Optimum	Slate	Medium to high

For the above reasons, there is a need for establishment of stands with predominant participation of the species, as sources of reproductive materials.

As source of reproductive materials in the NSFSPBB should be included the stands in SFS Berkovitza, stand 204sh$_2$; Vidin, stand 390b and 391b; Byala, stand 243v; Gurkovo, stand 30g (Fig. 2, Table 6).

From tree breeding point of view the young stands in SFS Kipilovo, stand 144b in North Bulgaria and SFS Gurkovo, stand 56v in South Bulgaria are interesting for future investigations (Tables 5 and 6, Fig. 2). After tracing their development, growth indicators and genetic-selection characteristics, they could be considered as further opportunity for enrichment of the Bulgarian Forestry Seed Production Base from Norway maple.

The results shows that the number of valuable from selection point of view stands with predominant participation of *Acer platanoides,* is limited, especially in South Bulgaria. Meanwhile, the presence of valuable phenotypes, requires their preservation and wider use for production of seedlings for forestry and urban planting. For these reasons we suggest two plantations to be established by grafting for seed production for the needs of North and South Bulgaria and Moesian and Thracian forest areas, respectively.

The establishment of vegetative plantations for seed production in the other hand requires investigation of possibilities for cloning (*in vivo* or *in vitro*) of mature, valuable from selection point of view individuals, with high genetic potential.

Table 6. Geographic coordinates of the studied Norway maple stands.

State forestry Service	Forest stand	Longitude	Latitude
Botevgrad	246d	23°49'33.76"	42°51'20.63"
Balchik	39m (part)	28°21'26.03"	43°27'39.13"
Kotel	3p	26°19'23.52"	42°54'06.53"
Tzonevo	80a	27°27'34.56"	42°54'45.04"
Borima	92s	24°21'26.29"	42°56'42.65"
Aitos	160b	27°21'26.29"	42°54'52.76"
Byala	39g	25°46'09.60"	43°23'03.30"
Tran	148g	22°33'17.13"	42°43'29.10"
Smyadovo	11d	26°54'46.92"	43°02'19.05"
Berkovitza	204 sh$_2$	23°14'44.58"	43°11'10.54"
Vidin	390b, 391b	22°24'01.97"	43°44'22.52"
Byala	243v	26°00'37.84"	43°28'53.76"
Gurkovo	30g (part)	25°40'27.24"	42°42'21.56"
Kipilovo	144b	26°23'01.99"	42°51'40.46"
Gurkovo	56v	25°39'43.62"	42°47'08.02"

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THE EFFECT OF GAP SIZE AND SHAPE ON THE SUCCESS OF NATURAL REGENERATION IN ORIENTAL BEECH (*FAGUS ORIENTALIS* LIPSKY) FOREST STANDS IN THE BARTIN-HASANKADI DISTRICT IN TURKEY

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Abstract

In this study, which has been carried out in natural beech gap regeneration field in division 56c in oriental beech (*Fagus orientalis* Lipsky) forest in Bartın-Hasankadı Forest Range District Directorate, the relationship between the number of young beeches and gap shape, gap direction, and gap size has been investigated. According to the findings obtained, it was determined that there is a significant relationship between gap shape and the number of natural beech juvenilities ($P<0.01$). According to the result of Duncan test performed within this scope, in $P<0.05$ confidence level, during 4 years of investigation was determined that the beech juvenilities densely occur in oval-shaped gaps, followed by round-shaped and rectangle-shaped gaps, respectively. On the other hand, according to the bilateral regression analysis, it was determined that there is a 98% ($R^2=0.98$) linear relationship between the gap shape and the number of beech juvenilities. The relationships between gap direction and the number of beech juvenilities were examined in this research. According to the performed variance analysis ($P<0.01$), it was found that there is a statistically significant difference between gap directions. That is why, as a result of Duncan test performed at the confidence level of $P<0.05$, it was determined that the number of beech juvenilities is more dense in northern parts of the gaps, and consequently the north takes first place in terms of the number of juvenility, and that north is followed by west and east beech directions, respectively. When considering the result of bilateral regression analysis performed in this direction, it was determined that there is a 96% linear relationship ($R^2=0.96$) between the number of juvenility and the direction of gap. Accordingly, as the direction of the gap changes from shadowy to sunny exposures, significant decrease occurs in the number of oriental beech juvenilities. In this study carried out in division 56c in Hasankadı region, the relationship between the number of beech juvenilities located in various sized gaps and the size of gap was investigated, and it has been tried to determine the optimal gap size. Within this scope, 10 different gap sizes were examined in this research. As a result of performed variance analysis ($P<0.001$ confidence level), it was found that there are statistically significant differences among gaps in terms of the number of juvenilities in gaps. After determining this difference, Duncan test was implemented in order to categorize the various-sized gaps according to the number of juvenility. As a result of this test, it was determined that 400 m^2, 500 m^2 and 600 m^2-sized gaps are in 1st category in terms of the number of juvenility, while ones having sizes of 100 m^2, 200 m^2 and 300 m^2 are in 2nd category, and the ones having sizes of 700 m^2, 800 m^2, 900 m^2 and 1000 m^2 are in 3rd category.

Key words: gap direction, gap size, gap shape, oriental beech, natural regeneration.

Indtroduction

It has been determined by many researchers that gap dynamics are very effective on the success of natural gap regeneration efforts performed within the scope of nature-friendly forestry approach in recent years (Mataji et al. 2006). Thus, the different juvenility dynamisms arising depending on sizes, shapes and directions of the gaps occur as a result of this situation (Karlsson et al. 2006). Different gap sizes, shapes and directions directly affect the success of natural regeneration effort especially on species growing slowly in juvenility period (Madsen et al. 2006). In beech forests, which grow slowly in juvenility period, requirement of upper and side protector shelter effect, and rehabilitating the forest soil, the natural regeneration efforts in recent years are carried out in gaps in accordance with nature-compliant silviculture (Özel 2007). In natural and artificial gap regeneration studies performed in both common beech and oriental beech forests, important problems are experienced in determining the size, location and shape of the gap (Diaci 2002). Similar problems have been observed in natural and artificial gap regeneration efforts performed within the Turkish-German Forestry Project in oriental beech forests in Turkey, and many unsuccessful efforts have been made (Özel 2007). In this study carried out in division 56c in Bartın-Hasankadi region, natural regeneration gaps have been opened in various sizes and shapes in order to profit from good-seed year occurred in beech of region in 2010, and the number of beech juvenilities in gaps have been counted for 4 years, and their locations have been determined.

Material and Method

Material

The Hasankadi Forest Range Directorate located within the territorial borders of Kozcağız district of Bartın is administratively affiliated with Bartın Forest Directorate. Planning unit is located in sheets numbered F29-a1, F29-a2 and F29-a4 in 1/25,000 scaled topographic Zonguldak map. Accordingly, Hasankadi region is located between 32°27'55" – 32°40'43"E and 41°29'18" – 41°22'18"N. The horizontal distance of the unit from sea is 50 km. According to the forest society classification performed by Mayer and Aksoy (1998), the forests of Hasankadi planning unit is in *northwestern euxin* forest sub-division of *euxin* forest division.

Being under the influence of the western Black Sea Climate (IIc), Hasankadi region has no meteorology station. That is why, the precipitation and temperature values required in order to draw the climate Walter diagram have been calculated from long-term average data of the nearest Bartın Meteorology Station (32 m a.s.l.). For this purpose, the data obtained from meteorological station have been interpolated for Hasankadi region having average altitude of 789 m. Accordingly, the mean annual and monthly precipitation values of Hasankadi Region are presented in Table 1.

The mean annual and monthly temperature values of Hasankadi region are presented in Table 2.

When the values in Table 2 are evaluated, it is seen that the mean annual temperature of Hasankadi region is 10.6 C, while the lowest mean temperature belongs to Janu-

Table 1. Mean monthly and annual precipitation values of Hasankadi Forest Range District.

Location	Altitude, m	Mean precipitation, mm												Annual
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Bartın	32	115.4	86.5	72.7	57.8	53.9	69.8	66.5	85.3	85.7	100.7	117.6	128.2	1040.1
Hasankadi	789	149.4	120.5	106.7	91.8	88.0	103.9	100.6	119.4	119.8	134.8	151.7	162.3	1448.9

Table 2. Mean monthly and annual temperature values of Hasankadi Forest Range District.

Location	Altitude, m	Mean Temperature, °C												Annual
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Bartın	32	4.1	4.8	7.2	11.4	18.4	19.7	21.6	21.3	17.6	13.4	9.3	7.4	12.9
Hasankadi	789	0.0	1.2	4.2	8.5	12.4	17.8	19.8	19.7	16.0	11.7	7.4	3.5	10.6

ary (0.0 °C) and the highest one belongs to July (19.8 °C) and August (19.7 °C). The growing period duration in research field is 6 months (May–October). The climate diagram of Hasankadi prepared according to Walter method is presented in Figure 1.

The geologic structure in Hasankadi region has been formed in cretaceous and sub-cretaceous periods of II. Time (Mesozoic). That's why, bedrocks in the region have metamorphic and sedimentary structure. Especially in steep parts of the region, there are calcareous, lime, marl, schist and flysch structures. In less-inclined parts, there are sandstone and conglomerate formations (MTA 2012). Also in existing forest management plan and detailed silviculture plan, it is reported that the general soil structure of Hasankadi Forest Range District has stony, mildly deep, alkaline, sandy lime, loamy lime, and sandy loamy lime texture (Anonymous 2014).

Division 56c of Hasankadi is in II site class, and the actual stand type is Knd_1. Having west and northwest exposure, 56c has the 1330 m altitude, and the land slope

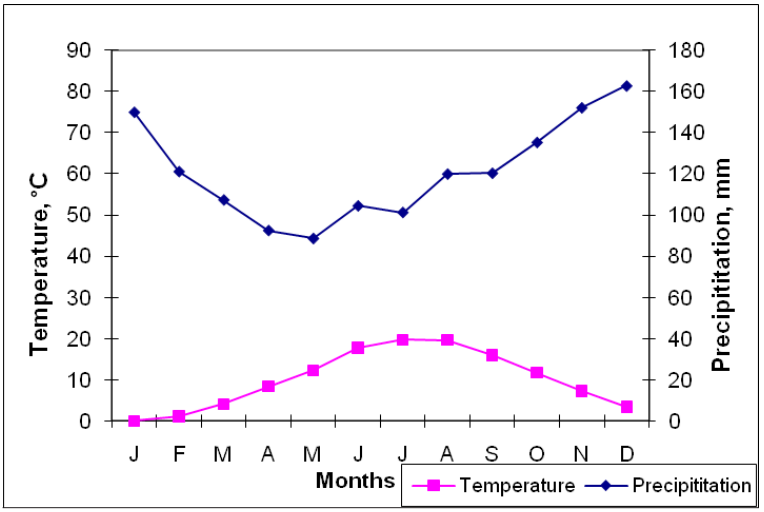

Fig. 1. The climate diagram of Hasankadi prepared according to Walter method.

varies between 30 % and 65 %. In this division, 2 gaps having 5.0 ha area have been opened in 2010, and the natural gap regeneration effort has been made. In 56c division, the insemination cutting has been performed in September. In this insemination cutting, a total of 14,516 m^3 final products have been obtained from beech. After the insemination cutting, a land preparation consisting of living cover removal and soil processing has been performed. In living cover removal processes, the rhododendron existing prevalently in forest has been cut into lines having 3 m of width, and the cutting has been performed at the level of soil surface. Then the cutting residuals have been gathered as 1m height clusters. The soil processing has been carried out in lines, where the living cover has been removed, via hoes.

Method

The beech regeneration gaps in 56c division, where the study has been carried out, have been shaped as oval, round, and rectangle through the insemination cutting in year 2010 (Figure 2).

On the other hand, 10 different gap sizes have been examined for each of gap shapes as I Gap: 100 m^2, II Gap: 200 m^2, III Gap: 300 m^2, IV Gap: 400 m^2, V Gap: 500 m^2, VI Gap: 600 m^2, VII Gap: 700 m^2, VIII Gap: 800 m^2, IX Gap: 900 m^2 and X Gap: 1000 m^2. Since the first germinations in 2011, the sapling counting has been carried out in 4 different directions (east, west, north and east) in gaps having various shapes and sizes. In order to determine whether there is a difference between gap shapes and gap sizes from the aspect of the number of juvenility, which is one of the most important criteria of success especially in natural regeneration efforts, variance analysis (ANOVA) and Duncan test have been applied. Also, in order to determine the relationships between gap shape and size and direction variables and the number of juvenility, the bilateral regression analyses have been carried out. SPSS statistical package software has been used in statistical analyses.

Result and Discussion

In close to nature silviculture implementations based on protecting the ecological balance and biodiversity in natural and artificial regeneration efforts carried out in order to ensure the sustainability of forests being the most important resource which can renew itself naturally, the shapes, sizes and directions of gaps have direct effect on success of regeneration efforts because regeneration efforts are made

Fig. 2. The front section of opened gaps' shapes (a: Oval, b: Round, and c: Rectangle).

in small-sized areas (gaps) (Reza 2004, Peter 2004, Lars and Burghard 2004). In natural gap oriental beech regeneration experiment established in Hasankadi Forest Range District, the relationship between the shape of gap and the number of juvenility has been investigated firstly. As a result of variance analysis implemented for this purpose, it has been determined that there is a significant relationship between the gap shape and the number of juvenility (P<0.01). As a result of Duncan test performed within this context, it has been found during 4 years of investigation on oriental beech juvenilities that the juvenilities are seen frequently in oval-shaped gaps, and this is followed by circle- and rectangle-shaped gaps, respectively (P<0.05) (Figure 3).

When Figure 3 is interpreted, it is seen that there is a 98% linear relationship between gap shape and the number of beech juvenilities as a result of bilateral regression analysis (R^2=0.98). In a study carried out on this topic on common beech in Germany, it has been determined that the beech juvenilities showed more frequent distribution in gaps opened in oval and diamond shape because the life-environment and the light physiology provide better conditions in these shapes rather than round, square- and rectangle-shaped gaps (Lüpke 2006, Madsen et al. 2006, Mataji et al. 2006).

In this study, the relationship between the gap direction and the number of beech juvenilities has been examined as well. As a result of variance analysis (P<0.01), it has been determined that there is a statistically significant relationship between gap directions. That's why, as a result of Duncan test (P<0.05), it has been found that the number of beech juvenilities is more dense in northern regions, and consequently, north takes the 1st place in terms of the number of juvenilities, and is followed by south, west, and east, respectively (Figure 4).

Considering the results of bilateral regression analysis presented in Figure 4, it is seen that there is a 96 % linear relationship between the number of juvenilities and the direction of gap (R^2=0.96). Accordingly, as the direction of gap changes from shadowy exposures to sunny exposures, the significant decrease occurs in the number of juvenilities of oriental beech (Figure 5).

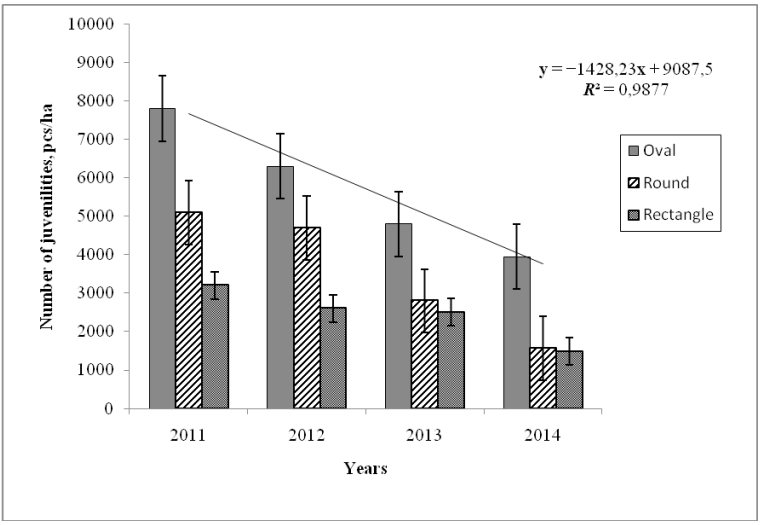

Fig. 3. The relationship between gaps shapes and the number of beech juvenilities.

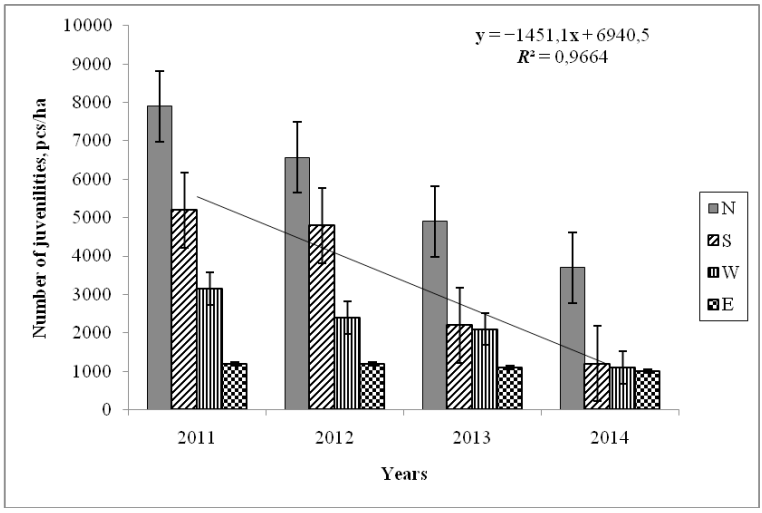

Fig. 4. The relationship between gap directions and beech juvenilities.

Thus, the best growth conditions of oriental beech consist of shadowy exposures, deep, organic-matter-rich, moist, sandy-loamy-lime textured soils (Ata 1981, Çepel 1982, Peters 1992, Agestam 1995, Barnes et al. 1998). In another research on this topic carried out in Turkey's Bartın and Devrek regions, it has been determined in natural beech gap regeneration study that juvenilities comes more frequently in significantly shadowy exposures (N, NE and NW), and that significant drying indications are observed in beech juvenilities in sunny exposures (Özel 2007). On the other hand, in a study on oriental beech gap regeneration fields in Iran, it has been found that the number of beech juvenilities in north and east directions having the optimum ecological conditions for regeneration are higher, and those juvenilities can retain in land (Talebi 1995, Schütz 1999, Mataji et al. 2006,

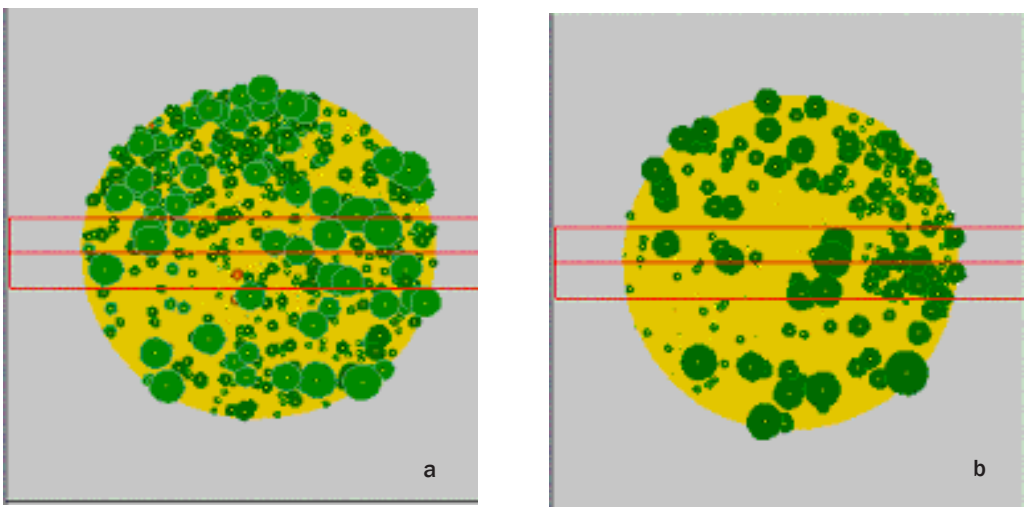

Fig. 5. The distribution of juvenilities in gaps located in shadowy (a) and sunny (b) exposure.

Shanjani et al. 2011). In regeneration efforts made according to both classic and close to nature silviculture studies, there is a very strong relationship between the size of regeneration area and the success of regeneration (Çolak et al. 2003). Especially from the aspects of easy organization and the optimum transportation opportunities, the most appropriate size of regeneration field should be determined (Ata 1995, Genç 2004). In this study carried out in division 56c in Hasankadi region, the relationship between beech juvenilities in the gaps opened in various sizes and the size of gaps has been examined and it has been tried to determine the optimal gap size. Within this scope, 10 different gap sizes have been examined. As a result of performed variance analysis (P<0.001 confidence level), it has been found that there are statistically significant differences among gaps in terms of the number of juvenilities in gaps. After determining this difference, Duncan test has been implemented in order to categorize the various-sized gaps according to the number of juvenility. Then, as a result of this test, it has been determined that 400 m^2, 500 m^2 and 600 m^2-sized gaps are in 1st category in terms of the number of juvenility, while ones having sizes of 100 m^2, 200 m^2 and 300 m^2 are in 2nd category, and the ones having sizes of 700 m^2, 800 m^2, 900 m^2 and 1000 m^2 are in 3rd category (Figure 6).

According to Figure 6, considering the ecological conditions in 4th, 5th and 6th Hasankadi regions taking place in 1st category as a result of Duncan test, they constitute the optimal gap sizes. In a study carried out on this topic in oriental beech forest in Hazar Sea's shore in Iran, it has been determined that the optimal regeneration gap size varies between 300 m^2 and 700 m^2 (Mataji et al. 2006, Sefidi et al. 2011). Hence, in another study carried out in western Black Sea region, it has been determined that juvenilities cannot find adequate amount of living space in gaps up to 300 m^2, they cannot profit optimally from equal shelter situation especially, and the living cover problem arises in beech gap regeneration fields larger than 600 m^2 because equal insemination cannot be ensured (Özel 2007).

Suggestions

In ensuring the sustainability of forests of oriental beech, which is one of the original forest tree species of Turkey, the close-

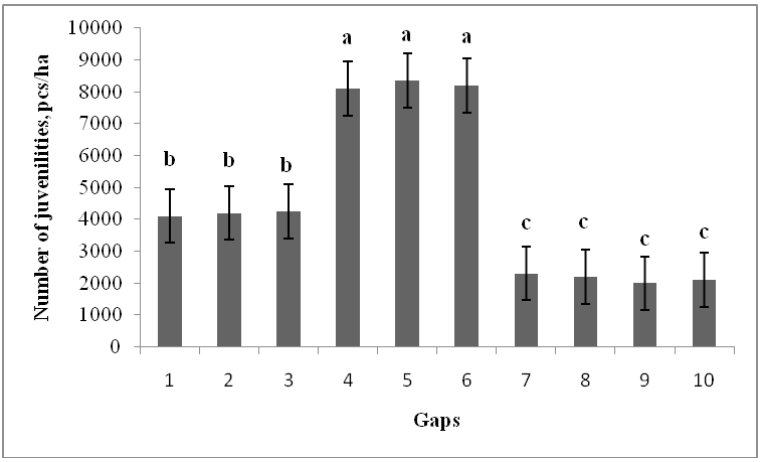

Fig. 6. The relationship between gap sizes and the number of juvenilities.

to-nature silviculture approach based on actual ecological balance should be adopted. In this context, the regeneration studies should be carried out in smaller lands and as smaller gaps. The shape of gaps in those gap regeneration efforts should be close to oval in order to profit from equal shelter situation and optimum light conditions. Otherwise, the possibility of important problems in retaining of beech juvenilities in land increases because the enough profit cannot be obtained from soil moisture and optimal light conditions. On the other hand, by ecological requirements of species, it will be better to open the gaps especially in shadowy exposures, to ensure that the stand closure is not so ruined if the gaps have to be opened in sunny exposures and the regeneration has to be carried out in that medium, and to protect the equal-shelter situation. This situation is especially important in order for living cover layer consisting especially of rhododendron not to cover the surface of the land. On the other hand, the criteria of "regeneration area size", which always had important effect on the success of regeneration efforts, also affects the success of gap regeneration studies being results of close to nature silviculture approach. That's why, it would be better to determine the optimal gap size by taking the actual ecologic conditions in natural and artificial gap regeneration studies and the silvicultural requirements of species into account. Hence, in parallel with the results obtained from this study, choosing the gaps size as 400-600m^2 for natural gap regeneration activities on beech in regions having ecological conditions similar with Hasankadi region will be useful for both controlling every phase of work organization and placing and holding the oriental beech juvenilities healthy in the regeneration field.

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EFFECT OF DIFFERENT SALT TREATMENTS ON SEED GERMINATION CHARACTERISTICS OF JUDAS TREE (*CERCIS SILIQUASTRUM* L.)

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Abstract

Seeds of Judas tree (*Cercis siliquastrum* L.) are characterized by coat-imposed dormancy related to the hardness and impermeability of their coat, and by endosperm dormancy due to the presence of ferulic acid around the seed endosperm, acting as chemical inhibitor. Some compounds including nitric acid gas, NO, NO_2^-, NO_3^-, nitrogen dioxide, ammonium, azide and cyanide stimulate germination process of different species. The present study was conducted to evaluate the effect of seed priming technique on some morphological characteristics of *Cercis siliquastrum* seeds. The results showed that seed priming with boiling water and nitrogenous compound could improve seed germination characteristics. Seed germination and survival were significantly affected by priming treatment with boiling water and chemical salts ($p < 0.001$). The greatest germination rate was observed with 500 mM KNO_3 for 48 h, while seed germination speed and shoot dry weight were maximized with 100 mM NH_4NO_3 for 48 h, vigor index with 500 mM NH_4NO_3 for 24 h and root dry weight with 100 mM NH_4NO_3 for 24 h. In addition, sodium chloride and potassium chloride treatments could not improve the germination characteristics and seedlet survivals of *Cercis siliquastrum.* These results confirmed that application of boiling water treatment and nitrogen-containing compounds could enhance germination rate and further seedling quality, and these treatments are thus extremely recommended in nurseries for improving seedling yield.

Key words: breaking dormancy, halopriming, root dry weight, salt solution treatment, shoot dry weight, vigor.

Introduction

Increasing global consumption of natural resources and ecological degradation, the annual net loss of world forest lands has reached 5.2 million hectares in the first 10 years of 21st century (FAO 2011). For example, the amount of forest degradation in Iran during last years has reached 2 million hectares (Kouhgardi et al. 2012). Hence, afforestation projects are very important in forest management of arid and semi-arid areas (Jazirei 2001). For this purpose, nurseries must produce high quality seedlings. This is particularly important for species having hard physical and physiological dormancy, like Judas tree (Dehghani 2005).

Cercis siliquastrum belongs to the subfamily Caesalpinioideae of the large plant family Fabaceae (Leguminosae). Genus *Cercis* currently includes about 10 recognized species scattered widely across the warm, north-temperate zones of North America and Eurasia (Fritsch et al. 2009). *Cercis siliquastrum* is native in southern Europe, the Crimea and Western Asia. In spite of being mostly a multi-stemmed tree, it can reach a height of 12 m in cultivation, albeit most individuals do not exceed 5 to 7 m (Raulston 1990). Flowers open at the beginning of spring, before the leaf flushing. Fruits mature at the end of summer or in autumn and remain on the plant for a long period of time. In the natural range of distribution of the species most of the annual rainfall (700–1000 mm) occurs between November and March, and only 5 % between May and September. It grows well on a variety of soil textures but performs best in soils with a pH above 7.5. It can tolerate some nutrient deficiencies and its growth is maximized in full sun. In Iran, *C. siliquastrum* is suitable for parks and gardens, and can be potentially used as a landscape tree, and as a phytoremediation measure against, for example, heavy metal deposits and dust storm (Yaşar et al. 2010). This species is well adapted to semi-arid conditions and can withstand hot dry summers provided that soil moisture is adequate in winter and spring. Judas trees can have many other applications such as border trees, for erosion control and windbreaks (Gebre and Karam 2004, Zahreddine et al. 2007).

Dormancy corresponds to a state of apparent metabolic arrest during which the normal progression of life activities and development is dramatically reduced or brought to a halt. Dormancy facilitates the survival of organisms exposed to environmental conditions that cannot support the regular course of life (Baskin and Baskin 1998). It can be regulated by the environment or by the seed itself. If a seed is not supplied with sufficient moisture or proper temperature, oxygen and light, its germination will be inhibited. Two types of dormancy are generally recognized: seed coat or external dormancy and internal (endogenous) dormancy. However, seeds of some species exhibit the so-called double dormancy, which is a combination of the two. To achieve germination in a case of double dormancy, seeds must be first scarified and then stratified for the appropriate prolonged period of treatment. If the treatments are administered in reverse order, the seeds will not germinate. After these treatments, seeds can be sown under proper environmental conditions for germination.

The seeds of Judas tree have double dormancy due, on the one hand, to the hardness and impermeability of the seed coat (Martinucci et al. 1985) and, on the other hand, to the presence of ferulic acid in the endosperm that acts as a chemical inhibitor (Pipinis et al. 2011). The dormancy of the *C. siliquastrum* seeds can be relieved by integument scarification. Conventional propagation requires different treatments because of the physical and physiological seed dormancy (Zencirkiran et al. 2010, Pipinis et al. 2011). Many studies have been conducted to break the dormancy of Judas tree seeds. Geneve (1991) and Dirr and Heuser (1987) tried to break the dormancy by cold stratification to allow imbibitions of the hard seed coat, but this method necessitates long periods of cold exposure to improve its efficiency. Also, while acid treatment of Judas tree seeds with combined effects of sulfuric acid and stratification resulted in high germination proportion, this method produced negative effects on seedling growth rate (Frett

and Dirr 1979, Liu et al. 1981) and is very time consuming. Over the last years, a new method has shown promising signs to improve the break of dormancy of tree seeds and the growth of seedlings (Bradford et al. 1990). During osmotic priming and/or halopriming, ions of potassium nitrate, sodium chloride, potassium chloride, sodium nitrate, calcium nitrate and ammonium nitrate solutions accumulate within the seeds and increase water absorption by reducing water potential (Parera and Cantliffe 1994). Successful results have been obtained with beans (Azooz 2009) and maize (Mehdi et al. 2008) under saline conditions. The advantages of halopriming in improving germination efficiency (Taylor et al. 1998), speed of germination (Bhan and Sharma 2011), growth rate (Guo et al. 2012), uniformity of germination and seed ling quality (Basra et al. 2005), popularized the application of this seed treatment in forestry.

Seeds of *C. siliquastrum* have a deep dormancy and are hard to germinate especially when dried. In this study, we investigated the simultaneous effects of boiling water and potassium nitrate, sodium chloride, potassium chloride, sodium nitrate, calcium nitrate and ammonium nitrate treatments on breaking the double dormancy and on germination of Judas tree seeds. The results could have potential to find an efficient and functional way to increase their germination.

Materials and Methods

Seed physical-and-chemical properties

The seeds of Judas tree used in this study came from the Central seed center of Caspian (Amol). Seed physical-and-chemical characteristics are presented in Table 1.

Table 1. Characteristics of the seed lot from Amol Caspian seeds Centre.

Species	Origin	Latitude	Longitude	Altitude, m	Climate	Viability, %	Humidity, %	Numbers per 1 kg	Weight of 1000 seeds, g	Purity, %
Cercis siliquastrum	Zanjan, Iran	36°66' N	48°48' E	1663	Semiarid ultra cold	85	4.4	36630	27.7	97

Seed treatments and germination tests

We selected seeds to homogenize their size and shapes before applying the thermo-halopriming treatments, randomly in order to their germination test. The seeds were soaked for 5 min in a solution containing 2 $g \cdot l^{-1}$ of carboxin thiram for disinfection and then washed with distilled water. After seed disinfection, they were put in boiling water whose temperature was then decreased to room temperature over a period of 24 h. Thereafter, to carry out halopriming, the seeds were soaked for 2 different periods (24 and 48 h) in solutions with three different osmotic potentials (100, 250 and 500 mM) produced by 6 chemical salts (potassium nitrate, sodium chloride, potassium chloride, sodium nitrate, calcium nitrate and ammonium nitrate). Seeds were then washed with distilled water and air dried. In addition, 2 non-priming treatments (soaked in boiling water for 24 and 48 h) and 1 control treatment (without soaking and priming) were

Table 2. The studied traits and calculating.

Germination indices	Equation
Germination rate	$GR = \frac{n}{N} \cdot 100$
Germination speed (Maguire 1962)	$GS = \sum \left(\frac{n_i}{t_i} \right)$
Mean time to germination (Abdul-Baki and Anderson 1972)	$MTG = \frac{\sum (n_i \cdot t_i)}{\sum n}$
Vigor index (Abdul-Baki and Anderson 1972)	$VI = (RL + SL) \cdot \frac{GP}{100}$

Note: n – the total number of seeds germinated in the period; N – the number of seeds planted; t_i – the number of days after the onset of germination; n_i – the number of germinated seeds in specified period of t_i; *RL* – mean or average rootlet length; *SL* – mean or average stem length; *GP* – percentage of seed germination.

applied to other groups of seeds. All treatments were conducted in a completely randomized design with 4 replications and 25 seeds within each treatment of each replication. After the application of each treatment, the seeds were placed on disinfected 9-cm glass Petri dishes with 2 layers of filter paper, each Petri dish containing 25 seeds. The Petri dishes were transferred to a germinator set at a temperature of 20 °C, with a 16:8 light period, 1000 lux light intensity and 60 percent humidity (ISTA 1985). The filter papers were replaced every 3 days to prevent contamination with fungi. We considered that seed germination occurred when radicles emerged from the seed coat and were at least 2 mm in length (Bradford et al. 1990). Seed germination was recorded daily during a period of 30 days, i.e. well after maximum germination was obtained.

Calculated variables and statistical data analyses

The following germination parameters were calculated: germination percentage (*GR*), germination speed (*GS*), mean time to germination (*MTG*) and for the VI calculation, after 30 days based on formulas presented in (Table 2).

Also, after 30 days, 10 cotyledons were randomly selected from each treatment and were used to measure growth characteristics such as shoot and root length using an electronic caliper with an accuracy of 0.01 mm, and fresh and dry weight of shoots and roots. Analyses of variance (ANOVA) were performed using the SPSS 16.0 software. Post-hoc Duncan test was used to evaluate the differences among means at 5 % level of probability.

Results

Analyses of variance (Table 3) revealed that boiling water and chemical salt treatments significantly improved the seed germination and seedling survival ($p < 0.001$). Among the priming treatments, the highest seed germination rate (*GR*) was ob-

Table 3. Mean squares of analysis of variance (ANOVA) for seed quality traits evaluated after priming with six salt solutions during 24 and 48 hours.

Source of variation	df	Germination, %	Speed of germination, seeds per day	Mean time to germination, days	Shoot length, mm	Root length, mm	Vigor index	Shoot dry weight, mg	Root dry weight, mg
Salt	5	9520.44**	4.84**	339.70**	4631.10**	46.43**	4692.07**	1125.86**	75.73**
Time	1	1296**	1.20**	24.67^{ns}	236.68**	279.4**	1166.33**	28.78**	8.19**
Concentration	2	589.77**	0.18**	58.05**	65.32*	47.02^{ns}	216.16**	12.41**	3.09**
S×*C*	10	623.91**	0.50**	41.03**	133.59**	116.99**	275.73**	33.94**	3.64**
S×*T*	5	654.93**	0.62**	7.21^{ns}	220.05**	421.547**	451.01**	132.18**	7.23**
T×*C*	2	233.33**	0.18**	19.25^{ns}	82.24**	272.51**	316.51**	8.93**	2.11**
S×*T*×*C*	10	239.46**	0.24**	5.89^{ns}	243.86**	93.33**	184.312**	45.62**	4.09**
Error	108	28.14	0.02	10,61	14.55	24.80	7,14	0.00	0.00

Note: * – significant difference at $P < 0.05$; ** – significant difference at $P < 0.01$; *ns* – non-significant; *S* – salt; *T* – time; *C* – concentration.

served in the treatment using 500 mM of KNO_3 during 48 hours (64 %) whereas the lowest *GR* was observed with 100 mM of KCl during 24 hours (1 %) (Table 3).

No germination was recorded in the control treatment. Among the chemicals used for priming, KCl, NaCl and boiling water were associated with lower seed germination. Also, seed germination speed (*GS*) was improved with chemical and boiling treatments. The highest value of GS was observed for the treatment consisting of 100 mM of NH_4NO_3 during 48 hours whereas the lowest value was observed with 100 mM of KCl during 24 hours. In the case of the mean germination time (*MTG*), the lowest value was observed with100 mM of KCl during 24 hours and the highest value with 500 mM of NaCl during 48 hours.

The growth characteristics of seedlings improved in all priming treatments. The highest value of shoot length was observed with 250 mM of KNO3 during 24 h while root length and vigor index were maximized with 500 mM of NH_4NO_3 during 24 h and 500 mM of NH_4NO_3 during 24 h, respectively (Table 4). Also, maximum values of shoot and root dry weight were observed with 100 mM of NH_4NO_3 during 24 h and 500 mM of $CaNO_3$ during 24 h, respectively (Fig. 1 and 2).

Discussion

Some compounds, including nitric acid gas, NO, NO_2^-, NO_3^-, nitrogen dioxide, ammonium, azide and cyanide, have been found to stimulate the germination of different species (Bradford and Nonogaki 2007). Generally, pretreating seed resulted in better germination, establishment of seedlet and seedling production (Farooq et al. 2007, Harris et al. 1999). In the present study, we aimed to break dormancy of *C. siliquastrum* seeds, which are characterized by 2 types of dormancy, A: a primary dormancy resulting from their hard and impermeable coat (Riggio-Bevilacqua and Tornabuoni 1974), and B: a secondary dormancy (endosperm)

Table 4. Effect of boiling water and chemical treatments on seed germination and seedling survival.

Treatment	Time, h	Concentration, mM	Germination, % ± S.D.	Speed of germination, seed on day	Mean time to germination, days	Shoot length, mm	Root length, mm	Vigor index
Sodium chloride	24	100	6(2,3)no	0,0(0,02)hi	19(3,3)abc	17(3,3)jklmn	7(0,78)lm	1,45(0,23)opq
		250	7(2)mno	0,1(0,01)hi	16,8(4,5)bc	14,8(1,7) mnop	7,2(1,6)lm	1,54(0,18)opq
		500	9(3.8)lmno	0,1(0,07)hi	20,5(3,07)ab	16,4(3,9) klmno	7,9(2)klm	2,19(0,41)opq
	48	100	8(3,2)mno	0,1(0,10)hi	15,5(3)bcde	17,2(3,1)ijkmn	7,2(0,8)lm	1,96(0,3)opq
		250	8(3,2)mno	0,1(0,03)hi	17,5(3,6)abcd	12,3(3,3)p	6,3(0,19)m	1,46(0,51)opq
		500	9(3,8)lmno	0,1(0,06)hi	22(4)a	13,9(33,3)nop	6,6(1,8)lm	0,20(0,05)pq
Potassium chloride	24	100	1(2)o	0,02(0,04)i	3(6)g	0,00(0,00)q	0,00(0,00)q	0,00(0,00)q
		250	4(3,2)no	0,08(0,07)hi	10,5(7,1)ef	0,00(0,00)q	0,00(0,00)q	0,00(0,00)q
		500	2(2,3)no	0,03(0,04)i	6,75(7,8)fg	0,00(0,00)q	0,00(0,00)q	0,00(0,00)q
	48	100	2(4)no	0,03(0,07)i	3,25(6,5)g	0,00(0,00)q	0,00(0,00)q	0,00(0,00)q
		250	7(2)mno	0,12(0,05)hi	15,1(3,6)bcde	14,1(2,7)nop	9,9(2,4)hiklm	1,68(0,02)opq
		500	3(2)no	0,07(0,05)hi	7,5(5,4)fg	0,00(0,00)q	0,00(0,00)q	0,00(0,00)q
Sodium nitrate	24	100	17(2)jkl	0,32(0,05)fgh	15,5(0,05)bcde	19,5(2,2)jhijk	11,6(4,1)fghikl	5,30(0,92)mn
		250	22(2,3)hijk	0,43(0,16)fg	15,4(0,35)bcde	35,5(7,6)a	15(4,1)efgh	10,6(1,7)jk
		500	47(3,8)def	1,09(0,1)cd	13,7(0,97)cde	34,3(7,7)a	13,9(4,6)ef	22,7(4,4)bc
	48	100	20(5,65)ijk	0,43(0,16)fg	14(1,47)cde	27,4(3,2)bc	12,5(1,7)fghik	8(0,7)l
		250	19(2)ijk	0,32(0,02)fgh	16,7(1,9)abcd	29,2(2,4)defg	10,7(1,5) ghiklm	6,4(0,7)lm
		500	10(2,3)lmn	0,22(0,04)ghi	16,5(1,2)bcd	19,9(2,7)ghijk	9,3(1)hiklm	2,92(0,3)nop
Potassium nitrate	24	100	25(3,8)ghij	0,43(0,08)fg	16,5(1,1)bcd	12,4(1,5)p	5,4(0,42)hiklm	5,4(0,4)mn
		250	54(2.3)bcd	0.96(0.1)de	17.6(2)abcd	14.9(2.1) lmnop	13.5(1.2)hiklm	13.5(1.2)hi
		500	58(6.9)abc	1.19(0.26) bcd	16.3(0.46)bcd	13.4(3.5)nop	13(3.4)hiklm	21.5(11)de
	48	100	31(8.8)g	0.51(0.18)f	17.1(1.5)abcd	12.5(1.8)op	6.4(0.95)iklm	6.5(0.95)lm
		250	58(6.9)abc	1.11(0.12)cd	16.3(1.8)bcd	13.4(2.2)nop	12.3(1.5)klm	12.3(1.5)ij
		500	64(4.6)a	1.23(0.01)bc	16.4(1.3)bcd	12.9(1.8)op	13(1.4)ef	13 (1.4)hij
Calcium nitrate	24	100	54(6,9)bcd	1,42(0,2)ab	14.9(2.3)cd	28.6(2.5)b	18.9(2.88)c	25.6(1.9)d
		250	62(5.1)ab	1.64(0.4)a	14.3(1.5)cde	25(3.3)bcde	25.5(7.3)b	31.3(5)b
		500	42(9.2)f	0.78(0.1)e	15.8(1.9)bcde	21.6(2.9)efghi	27.4(6.8)ef	20.6(3.4)de
	48	100	32(8)g	0.54(0.1)f	17.2(0.3)abcd	18.7(3.9)hijkl	24 (8.3)cd	13.7 (2.67)hi
		250	30(6.9)gh	0.49(0.1)f	17.3(0.9)abcd	20.7(2.1)fghij	29.6(11.3)b	15 (3.5)gh
		500	30(5.1)gh	0.51(01)f	17.1(1.4)abcd	21.8(2)efghi	26.1(8.1)bc	14.4(2.8)hi
Ammonium nitrate	24	100	48(9.7)def	1.16(0.34)cd	13.7(0.7)cde	20.5(6.1)fghij	26.5(11.6)d	22.5(7.25)d
		250	45(10.5)ef	1.04(0.2)cd	13.4(0.9)cde	22.4(4.1) defgh	19.8 (8)de	19(5.15)ef
		500	60(3.2)abc	1.47(0.33)a	13.7(2.1)cde	26(4.4)bcd	35.6 (11.9)a	37(7.8)a
	48	100	52(5.6)cde	1.49(0.13)a	13.4(0.7)de	22.7(4.5)defg	18.5(5.3)d	21.4(2.7)de
		250	26(6.9)ghi	0.45(0.13)fg	17.9(1.8)bcd	18.1(6.4)ijklm	15.7(4.1)efg	8.8(2.1)kl
		500	46(5.1)def	1.16(0.26)cd	13.7(1.7)cde	24.3(6.6)cdef	13.3(5.5)fghi	17.3(2.35)fg
Boiling water	24	–	10(2.3)lmn	0.14(0.04)hi	17.9(1.8)abcd	14.7(3.7) mnop	14.7(3.7)cde	2.12(0.47)opq
	48	–	15(2)klm	0.21(0.03)ghi	18.7(0.4)abc	16.5(3.2) klmno	16.5 (3.2)f	3.43(0.57)opq

Note: Different letters indicate significant difference between seed treatment means according to Duncan's multiple range tests at the 0.05 significance level. Number in brackets represents standard deviation.

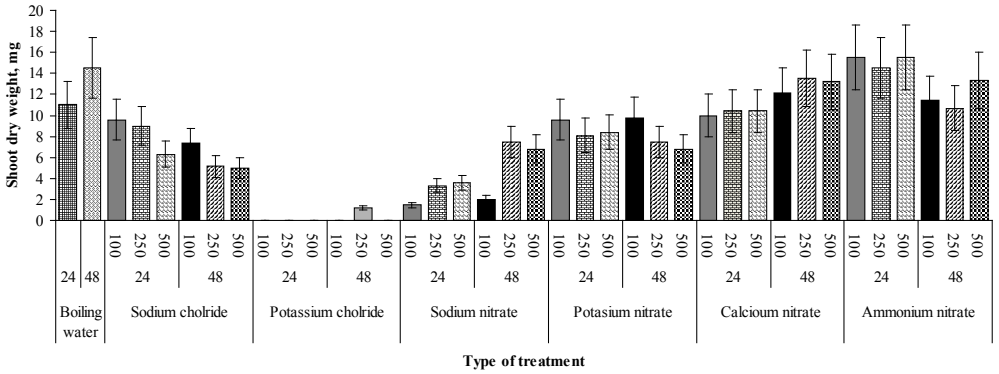

Fig. 1. Effect of different chemical treatments applied at various levels on shoot dry weight of primed and non-primed (boiling water) seeds (mean ± standard error).

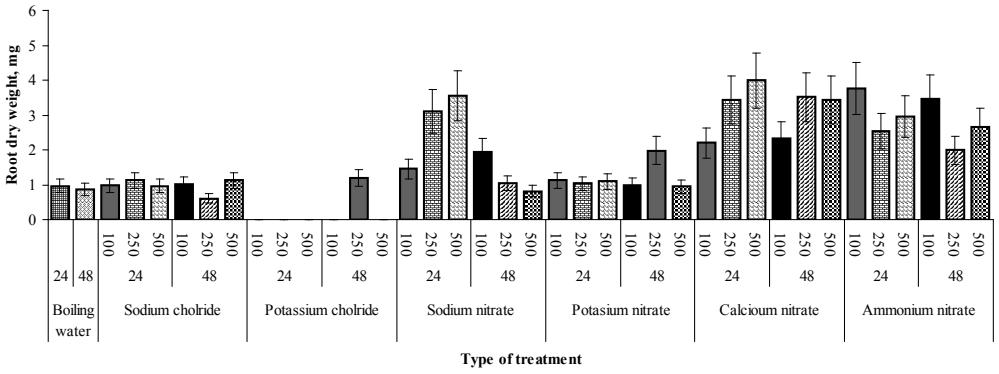

Fig. 2. Effect of different chemical treatments applied at various levels on root dry weight of primed and non-primed (boiling water) seeds (mean ± standard error).

caused by the presence of ferulic acid that inhibits the absorption of oxygen and water by the embryo.

Our results showed that salt treatments, differing in concentrations and time duration, significantly improved germination and primary growth of *C. siliquastrum* species. The highest germination percentages were found in scratching treatments with potassium nitrate and ammonium nitrate likely because of the presence of nitrite (NO_2^-) in these compounds (Sabina and Cornelia 2012). By altering the cell membrane, nitrate (NO_3^-) and nitrite (NO_2^-) allow materials to penetrate into the seed (Bethke et al. 2006) which, in turn, improve plant growth (Hendricks and Taylorson 1974). In addition, Roberts (1969) suggested that nitrogen-containing compounds could act as electron-accepting agents or could stimulate the transport of materials into the seed using NADPH oxidation[1]. These results are supported by many observations of the influence of nitrogen-containing compounds for stimulating the germination of various species (Stokes 1965, Bewley and Black

1994, Li et al. 2005).

The poor germination rate in seeds without any treatments could be explained by the physical characteristics of the seeds of Judas tree characterized by a thick crust containing several thick pectin and hemicellulose layers that become impermeable and hydrophobic during the last step of maturation (Comer 1976). In addition, the seed glazed layer prevents transporting oxygen and water into the seed endosperm (Riggio-Bevilacqua et al. 1985, Rascio et al. 1998). The highest germination rate was associated with ammonium nitrate, calcium nitrate, potassium nitrate, and sodium nitrate treatments. These results could be explained by the influence of boiling water to break seed dormancy and by the effect of nitrate to break endosperm dormancy and eliminate the ferulic acid layer (Bergmark et al. 1992). These results are consistent with Guo et al. (2012), who assessed halopriming technique using KNO_3 on germination of *Pinus bungeana* Zucc. ex Endl. seeds, and of Bhan and Sharma (2011) who worked with *Prunus armeniaca* L. using the same salt. Henig-Sever et al. (2000) concluded that NH_4^+ and NO_3^- exerted a positive effect on lipase activity of *P. halepensis* Mill. seeds and that these compounds degraded lipids and stimulated germination compared to other compounds.

The lowest average germination time was observed with the potassium chloride treatment which was also associated with the lowest germination percentage. Among nitrate treatments, the lowest average germination time was found with ammonium nitrate applied at different concentrations, but this result can be explained by the high germination rate associated with the use of the compound (Farooq et al. 2005). NaCl and KCl pretreatments did not improve germination of *C. siliquastrum* seeds compared to other nitrate and boiling water treatments. This could be explained by the fact that the cell wall of seed endosperm contains a chemical inhibitor (Martinucci et al. 1985) that is not affected by NaCl and KCl to protect the seed embryo from the toxic effect of Cl^- and Na^+ (Khajeh-Hosseini et al. 2003). These results are not consistent with Elouaer and Hannachi (2012) who observed better germination parameters of *Carthamus tinctorius* seeds following pretreatments using NaCl and KCl.

The better germination indices associated with treatments containing NO_3^- could be explained by the nitrate property to be a molecule carrier, which increases absorbed materials into the plant (Scheible et al. 1997). The higher viability index for seedlet obtained from ammonium nitrate and calcium nitrate pre treatments compared to other treatments may result from the improvement of seedlet length and germination percentage (Eskandari and Kazemi 2011). This result agrees with those of Ruan et al. (2002) who worked on *Oryza sativa* L. and observed a higher viability index associated with primed seeds compared to unprimed seeds. The better stem length emerging from seeds pretreated with sodium nitrate, calcium nitrate and ammonium nitrate could be explained by their rapid germination (Farooq et al. 2005). Also, it could be the result of the effect of the main nitrogen source, NO_3^-, on plant growth that produced amino acid and nitrogen-containing compounds through a decrease in nitrate reductase and other enzymes (Scheible et al. 1997, Wang et al. 2003). The improved root length of seeds pretreated with ammonium nitrate and other compounds could be attributed to

[1]Nicotinamide adenine dinucleotide phosphate.

the stimulating effect of NO_3^- on root growth (Hilhorst and Karssen 1992). Also, the use of nitrate-containing pretreatments to enhance water absorption of seeds could be considered as a factor explaining the fast appearance of roots and their rapid growth compared to seeds without priming treatment (Harper et al. 1977). The higher dry biomass of above- and below-ground parts of seedlets treated with nitrate-containing compounds could be explained by the improved growth of radicles and plumules (Sivritepe et al. 1999).

Overall, our results demonstrate that pretreating seeds with nitrate-containing compounds was highly efficient to stimulate and reinforce the germination and other physiological characteristics of *C. siliquastrum* seeds. Therefore, using boiling water treatment and nitrogen-containing compounds such as potassium nitrate and ammonium nitrate can enhance germination percentage and germination rate in such a way that these treatments could be used to increase the production efficiency of seedlings in nurseries.

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COMPARISON IN WOODY SPECIES COMPOSITION, DIVERSITY AND COMMUNITY STRUCTURE AS AFFECTED BY LIVESTOCK GRAZING AND HUMAN USES IN BEECH FORESTS OF NORTHERN IRAN

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Abstract

In the more forested areas of Iran, rural people are in close relationship with natural resources, especially forests. This close association endangers the dynamics and sustainability of forest ecosystems. Hence, we investigated the effects of grazing and human uses on woody plant diversity, composition and forest structure in beech forests of northern Iran. We thus compared a 50-ha area protected against livestock and human disturbances to a 50-ha unprotected area. In each area, we recorded tree species, diameter at breast height (DBH) of merchantable trees, and stem numbers of shrub species in 1000-m^2 plots established in a random-systematic sampling design. These data allowed us to compute diversity indices separately for tree and shrub layers. Results revealed that tree density, mean tree DBH and total basal area were significantly higher in the protected than in the unprotected area. However, in both the tree and the shrub layers, values of Shannon diversity, evenness index, richness, and shrub density were lower in the protected area than in the unprotected area. Because forest structure, composition and diversity are closely associated with human traditional activities, we recommend that conservation programs be implemented in collaboration with local people to help establish effective management aiming at providing services for local people while restoring these forests.

Key words: disturbance, floristic composition, forest structure, Iran, species diversity.

Introduction

Understanding the relationship between plant diversity and land use history can have important implications in forest management decisions, especially when these ecosystems were widely used by humans (Tálamo et al. 2012). Iran is an important source of plant diversity with 22 % out of 8000 species that are endemic. Hyrcanian forests are one of the main floristic regions in northern Iran. These forests are located on the northern slopes of the Alborz Mountains overlooking the Caspian Sea (Sagheb-Talebi et al. 2003). Among forest communities in

northern Iran, Oriental beech (*Fagus orientalis* Lipsky.) dominated stands are highly valuable because of their major contribution to carbon sequestration, socio-economic activities, soil protection and recreation resources (Wardle 1984). These forests correspond to an area of 565,000 ha in the province of Guilan and are subjected to commercial harvests although a small proportion has been protected or conserved. Approximately one-third of these forests have been destroyed in the last 35 years (Marvi-Mohadjer 2007). Nearly 87 % of the Iranian forest degradation was caused by human activities (Jazirei 2001), such as irregular grazing and wood consumption, and only 13 % by natural factors (Heydarpour Tutkale et al. 2008). The composition and diversity of plant communities in many of these natural ecosystems were considerably affected, and the extent to which these changes were significant depended on the intensity and frequency of degradation sources and on the ability of plant species to adapt to these new conditions (Herath et al. 2009).

The effect of human activities is exacerbated by livestock grazing, which affects 25 % of the earth's forest ecosystems (Asner et al. 2004). In the more forested areas of Iran, rural people are in close relationship with natural resources, especially forests (Reyers 2004). This close association endangers the dynamics and sustainability of forest ecosystems. Human activities in these areas can lead to loss of ecological resilience with forest cover destruction over the short term and flooding and erosion over the medium to long term. Ultimately, life conditions will be jeopardized in such forest ecosystems (Heydarpour Tutkale et al. 2008). During the process, grazing can change competitive balance between species (Jones et al. 2011), composition and abundance of plants, species dominance establishment of plant species (Bouahim et al. 2010), ecosystem processes and biodiversity (Polasky et al. 2011). These changes can progressively lead to unbalanced ecosystems, which can hardly revert to their initial state (Emlen et al. 1998). Therefore, conservation of forest biodiversity and structure has been considered as a management objective (Jonathan and Nicole 2005) and in the last few decades, especially after the Rio conference, the loss of biodiversity associated with human activities became a major source of concern for forest ecologists (UNCCD 2004). The ecological effects of grazing on biodiversity, forest structure and species composition have recently been studied and discussed, and different responses such as increase or decrease in richness, evenness and ecosystem functions have been observed in ecosystems submitted to grazing and human activities (Agra and Neeman 2012, Bouahim et al. 2010, Clark and Covey 2012).

Studying and surveying effects of livestock grazing and human uses on vegetation composition, diversity and community structure and acquire knowledge about these beech forests would yield important information, which is necessary to forecast forest composition, succession and determine the intensity of forest disturbance. Such studies could help to suggest initiate methods to adequately manage and reconstruction. We hypothesized that livestock grazing and human uses affected forest structure, composition and diversity in oriental beech forests. The specific objectives focused on (1) livestock grazing and human uses effects on forest structure, (2) livestock grazing and human uses effects on density and species com-

position in the tree and shrub layer, (3) livestock grazing and human uses effects on species diversity (richness and evenness). The results of this study are highly relevant to forest managers involved in decision making in similar forested areas.

Material and Methods

Study area

The study was conducted in a 100-ha forested area located in the Masal of Guilan province in northern Iran (37°14'00" to 37°19'20" N and 48°55'19" to 49°02'00" E). This area is characterized by a range of elevation from 300 to 2000 m a.s.l largely dominated by eastern slopes. Common forest soils are acidic and were deposited on parent materials composed of shill, sand stone and calcareous. Mean annual precipitation and temperature are 990 mm and 16 °C, respectively (information from station of Hydrologyand Meteorology Shanderman). While there is no permanent residential area in this region, dairy farmers and local people use the territory for animal husbandry during 2–4 months in spring and summer of each year. Over the years, the primary structure of these forests was modified because of disturbances such as heavy grazing by livestock, tree girdling, and excessive cutting of trees and shrubs to supply fuel wood. The forest is uneven-aged and is composed of mixed deciduous broad-leaved trees and sometimes of unmixed beech trees. A conservation program was initiated seven years ago by fencing about 50 ha of these forests to reduce the effect of grazing pressure and the entry of livestock and humans.

Data collection

Data collection was achieved in July 2012 in a protected area adjacent to an unprotected area, 50 hectares each, which were selected on both sides of a road. The protected and unprotected areas shared similar altitude, slope and aspect. In each area, we used a random-systematic sampling with a 100 × 200 m grid to locate 25 1000-m^2 circular plots (Zobeiry 2006). Then, in each plot, tree species were identified and diameter at breast height (DBH) was measured on trees larger than 7.5 cm in diameter whereas stems of each shrub species were counted (Adel et al. 2013). We also collected some variables that can affect woody species diversity (Arévalo et al. 2011) such as the litter depth at five locations (Adel et al. 2013), number of dead trees, percent cover of the tree canopy and the herbaceous layer (Deléglise et al. 2011).

Data analysis

Species richness, Shannon's diversity (Allred et al. 2012) and evenness (de Villalobos and Zalba 2010) indices were calculated for each layer using the Ecological Methodology software for Windows, version 6.0 (Krebs 1999). Pearson correlations were used to determine the degree of linear dependence between environmental factors and diversity indices for both protected and unprotected area (Chaturvedi et al. 2012). Kolmogorov–Smirnov test was used to verify the normality of data distribution and the Levene test was used to evaluate the homogeneity of variances. Non-paired *t*-tests were used for normally distributed data while a non-parametric equivalent (Mann-Whitney *U*-test) was used for non-normal data. These analyses were conducted with the SPSS 16.0 software.

Results

Floristic characteristics

Statistical analyses indicated that tree density (N·ha^{-1}) and the total basal area were significantly higher in the protected area than in the unprotected area. Conversely, the mean number of shrubs per hectare was statistically greater in the unprotected area than in the protected area (Table 1).

The same tree and shrub species were identified in both areas. Only three tree species were recorded in protected and unprotected areas: *Carpinus betulus* L.*, Alnus glutinosa* (L.) Gaertn. and *Fagus orientalis*. In the protected area, *Fagus orientalis* was more abundant (highest tree density) whereas in the unprotected area, *Carpinus betulus* was the dominant tree species. Density of *Fagus orientalis* and *Alnus glutinosa* species were significantly different ($P \leq 0.05$) between the protected and unprotected areas (Table 2).

Table 1. Characteristics of study areas (Mean ± Standard error).

Characteristics	Protected	Unprotected	*P*
Density of trees, N·ha^{-1}	13.8 ± 1.41	6.8 ± 0.88	0.000 **
Density of shrubs, N·ha^{-1}	10.96 ± 1.6	24.88 ± 2.88	0.000 **
Basal area, m^2·ha^{-1}	37.1 ± 0.31	17.1 ± 0.22	0.000 **

Note: ** indicates significant differences at the 99 % level.

Density of all shrub species was higher in the unprotected area than in the protected area. The total number of *Mespilus germanica* L., *Prunus divaricata* Ledeb., *Crataegus microphylla* C.Koch, and *Crataegus ambigua* A.K.Becker was significantly different between the two areas, although no statistical differences were detected for *Ruscus hyrcanus* Woron. and *Ilex aquifolium* L. (Table 2).

The DBH and the basal area of *Fagus orientalis* were higher area in the protected area than in the unprotected area. Mean DBH of *Carpinus betulus* and basal area of *Fagus orientalis* and *Carpinus betulus* were significantly different between the protected and unprotected areas (Table 3).

The number of trees in all diameter classes was higher in the protected area, although these differences were mostly apparent in the 35 to 60 cm classes. In the protected area, greater tree densities were observed in diameter classes 35 to 60 cm, which were twice the number of trees compared to the unprotected area. In the unprotected area, larger tree densities were observed in intermediate diameter classes (25–45 cm) and then in lower classes (10–20 cm). Lower tree densities were observed in higher diameter classes (> 60 cm) in both areas (Figure 1).

Biotic and abiotic factors

Among the studied biotic and abiotic factors, the mean number of dead trees per hectare and the canopy cover percentage were significantly larger ($P \leq 0.01$) in the protected area than in the unprotected area. In the unprotected area, percent of herbaceous cover and bare soil were higher than in the protected area, but these differences were not statistically significant (Figure 2).

Table 2. Density (N·ha^{-1}) and Standard Error (SE) of woody species in protected and unprotected areas.

Species	Life form	Protected		Unprotected		
		Mean	SE	Mean	SE	*P*
Fagus orientalis	Tree	107.2	14.06	30	7.04	0.000**
Carpinus betulus	Tree	11.2	5	30.8	1.25	0.1ns
Alnus subcordata C.A.Mey	Tree	14.4	4.47	3.2	6.82	0.04*
Mespilus germanica	Shrub	10.4	3.62	31.6	9.75	0.04*
Prunus divaricata	Shrub	30.8	6.7	80	14.8	0.004**
Ruscus hyrcanus	Shrub	10	4.7	20.4	6.1	0.1ns
Ilex aquifolium	Shrub	56.8	15.9	77.6	18.5	0.4ns
Crataegus microphylla	Shrub	0.4	0.4	19.2	5	0.001**
Crataegus ambigua	Shrub	0.8	0.5	18.88	7.75	0.02*

Note: Significant differences *$P < 0.05$, **$P < 0.01$, and ns – no significant.

Variation in diversity, richness and evenness

In both the tree and the shrub layers, values of the Shannon diversity and evenness indices as well as richness were lower in the protected area than in the unprotected area. However, the only significant differences ($p < 0.01$) between the protected and the unprotected areas were calculated for the diversity and richness indices in the shrub layer (Table 4).

In the tree layer of the protected area, evenness index was negatively correlated with the percent canopy cover, whereas the number of dead trees was positively and significantly correlated with all indices of diversity. In the shrub layer, the richness index was significantly and negatively correlated with the canopy cover, while the evenness index

Table 3. Diameter at breast height (DBH > 7.5 cm) and Basal area in Protected and Unprotected areas.

Species	DBH, cm			Basal area, m^2·ha^{-1}		
	Protected	Unprotected	*p*	Protected	Unprotected	*p*
Fagus orientalis	59.92	44.80	0.08ns	76.46	28.17	0.000**
Carpinus betulus	16.29	36.11	0.003**	5.67	10.76	0.004**
Alnus glutinosa	29.95	29.86	0.4ns	10.75	3.84	0.08ns
Total	35.38	34.52	0.8ns	92.88	42.78	0.000**

Note: Significant differences **$P < 0.01$, and ns – no significant.

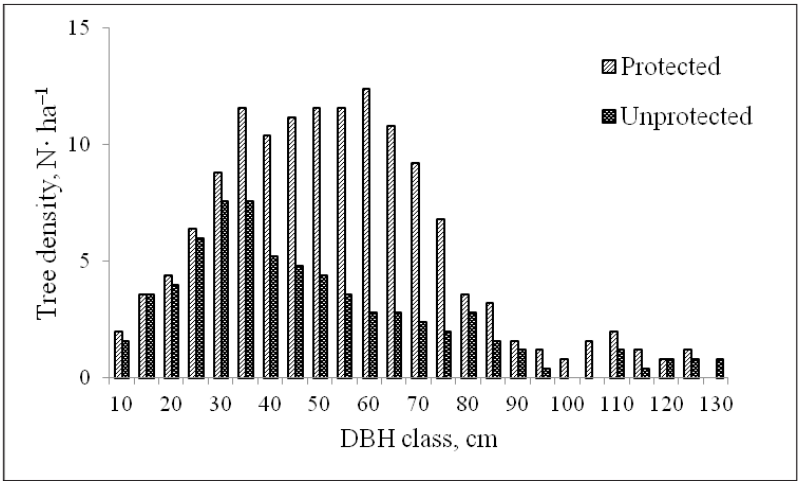

Fig. 1. Density-diameter distribution of trees in the two forest stands.

of the factors in the shrub layer. In the unprotected area, tree species richness was negatively and significantly correlated with the herbaceous cover, while the correlation between richness and evenness indices with the number of dead trees were positive and signifi-

was not significant correlated with any

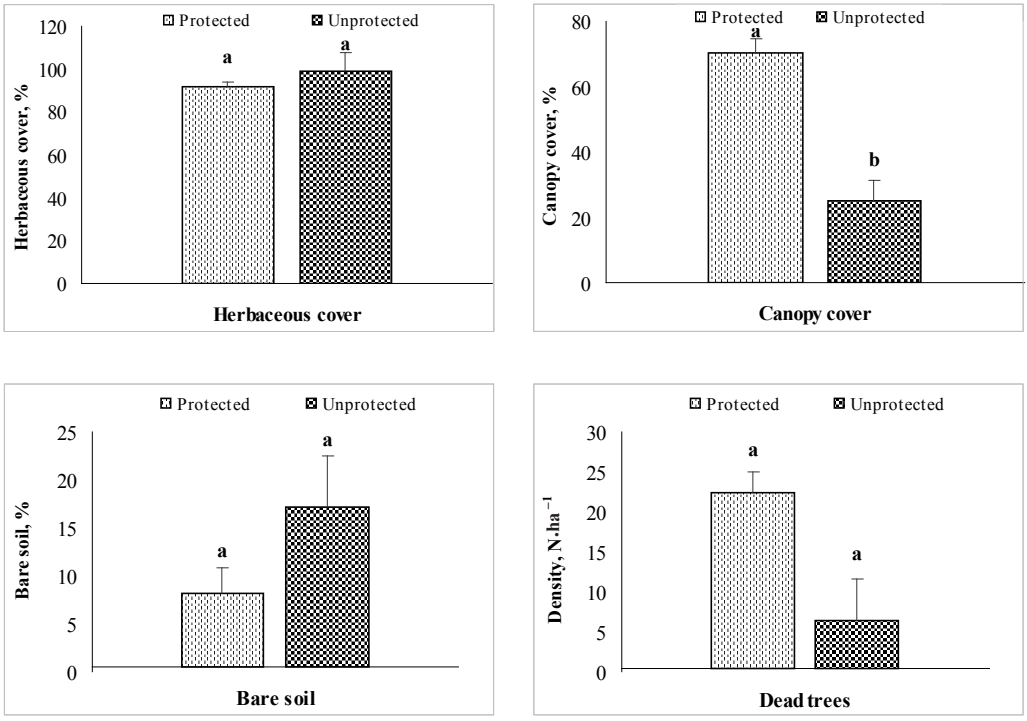

Fig. 2. Variability (Mean ± SE) in habitat variables between protected and unprotected areas.

Note: Different letters indicate significant differences at the 0.01 level.

Table 4. Statistical analysis (mean± standard errors) for diversity, richness evenness in tree and shrub layers in protected and unprotected areas.

Indices	Tree layer			Shrub layer		
	Protected	Unprotected	*p*	Protected	Unprotected	*p*
Diversity	0.67±0. 1	0.79±0.11	0.4	0.1 ±0.04	0.4 ±0.08	0.002**
Richness	1.72±0.15	1.84 ±0.16	0.5	2.4 ±0.17	3.5±0.32	0.003**
Evenness	0.77 ±0.114	0.9 ±0.119	0.2	0.77 ±0.09	0.80 ±0.11	0.8

Note: ** Indicate significant differences at the 99 % level between protected and unprotected areas.

Table 5. Pearson correlation coefficients between biotic and abiotic factors with diversity indices for woody species layers in protected and unprotected areas.

Factors	Protected				Unprotected			
	Tree		Shrub		Tree		Shrub	
	Richness	Evenness	Richness	Evenness	Richness	Evenness	Richness	Evenness
Canopy cover	0.54	–0.539*	–0.632*	–0.33	0.28	0.346	–0.570*	–0.63*
Dead trees	0.59**	0.642**	0.07	0.206	0.586*	0.804**	0.28	0.327
Herbaceous cover	0.212	0.225	0.347	0.40	–0.64**	–0.52	–0.277	–0.142

Note: * Indicates significant correlation at 0.05 level; ** indicates significant correlation at 0.01 level.

cant. In the shrub layer, large negative correlations were observed between canopy cover and both species richness and evenness, while correlations between the number of dead trees with richness and evenness was weakly positive (Table 5).

Discussion

Tree layer

Forest areas in northern Iran are commonly used for livestock grazing and by dairy farmers as forest pasture (Heydarpour Tutkale et al. 2008). In the unprotected area, people livelihood activities, such as grazing, lopping and felling of trees for fuel wood, girdling for fodder production and collection and dead trees reduced the density and frequency of tree species by creating micro-environmental heterogeneity (Kumar et al. 2004). However, tree species diversity, richness and evenness were higher in the unprotected area as already observed by Rutherford and Powrie (2010). These results can be explained by the establishment of light demanding species and to a more uniform distribution of individuals among species in the unprotected area. The heterogeneous species richness in the unprotected area has been caused in particular by the formation of a forest mosaic composed of patches with low and high tree diversity (Cadotte et al. 2002).

At the end of a natural succession process, the dominance of only one species is often reached, which also tends to be accompanied by few canopy openings, increasing stand density and thus poor tree diversity in response to the elimination or restriction of human interferences. In the protected area, *Fagus orientalis* was the dominant species and most plots were only composed of beech, this can explain the low diversity and richness index values in the protected area as it is the case when only one species constitutes more than 50–80 % of a forest canopy (Connell and Lowman 1989). In the unprotected area *Carpinus betulus* had the lowest density because of its poor ability to compete with *Fagus orientalis* and were thus gradually eliminated through competition. Unsuitable tree composition, low tree density and canopy openness caused by the removal and the natural mortality of dominant trees increase the availability of light and nutrients (Vockenhuber et al. 2011). However, grazing and other human disturbances can lead to changes in ecological conditions (Gorchov and Trisel 2003) which can modify the vegetation composition, particularly by promoting the establishment of invasive species (O'Brien et al. 2007, Vavra et al. 2007). However, in forests degraded by grazing and human uses, the establishment and development of *Fagus orientalis* was very difficult, which promoted the emergence of invasive species such as *Pteridium aquilinum* (L.) Kuhn, and *Sambucus ebulus* L. Therefore, evenness index in the unprotected area was higher due to reductions in dominance and in frequency of *Fagus orientalis* (Kupferschmid and Bugmann 2005), in competitive structure (Rutherford and Powrie 2010) and in canopy cover (Abanesi et al. 2005) as well as to the increasing dominance of *Carpinus betulus*. Destructive factors such as grazing and extensive tree removal promoted the establishment of this species because of its high seed production ability and its resistance to intense grazing (Akbarinia and Hukusima 1995).

The lower tree density observed in lower DBH classes as compared to intermediate DBH classes in the unprotected area can be explained by tree removal in lower DBH classes together with the increasing density of herbaceous species which reduce the establishment and the development of tree seedlings. Lower tree density in large diameter classes as compared to other DBH classes can be the result of tree senescence in the protected area (Lorimer et al. 2001) and by the removal of some of these trees by local people in the unprotected area (Schwartz and Caro 2003).

Shrub layer

The abundance of all shrub species, richness and evenness indices were higher in the unprotected area than in the protected area likely because of the ecosystem response to disturbances and to the establishment of shrub species resistant to grazing as observed by Onaindia et al. (2004) and Rodríguez-Soalleiro and Madrigal (2008), while de Villalobos and Zalba (2010) observed the contrary. Overall, the diversity of shrub species was higher than that of tree species (Kyde 1999) but shrub response to grazing was not identical among species (Archer 1989).

The high density of *Ilex aquifolium* in the protected area and *Prunus divaricata* in the unprotected area indicates that they were dominant species in their respective environment. The number of light demanding, deciduous species, such as

Mespilus germanica, Prunus divaricata, Crataegus microphylla and *Crataegus ambigua*, were higher in the unprotected area likely because they took advantage of the canopy openings related to dominant tree mortality (Rees and Juday 2002). Indeed, these conditions increase light availability to the forest floor which, in turn, positively influence nutrient cycling (Castedo-Dorado et al. 2012). However, disturbances such as livestock trampling can restrict the plant access to soil resources, facilitating the establishment of invasive woody species (Vavra et al. 2007).This can explain the negative correlation between tree canopy cover and shrub species richness in both areas (O'Brien et al. 2007). On the other hand, the changes in abundance of evergreen species such as *Ruscus hyrcanus* and *Ilex aquifolium* between protected and unprotected areas were less pronounced than those of deciduous species likely because of a lower browsing rate due to their high lignin content and the presence of thorns (Agra and Neeman 2012). In addition, these species are shade tolerant and can thus survive and develop under the extensive canopy cover of the protected area (Legare et al. 2002).

Conclusion

Forest ecosystems in northern Iran are used in various ways by local people. Furthermore, forest structure, composition and diversity are closely associated with grazing and other disturbances caused by human activities and these factors have created considerable negative effects on ecological processes. The overall results indicated that conservation affected the quality and quantity of the protected area, leading to a decreased diversity of tree and shrub layers, which demonstrates that forest protection and reaching to the climax stage are not necessarily associated with maximum biodiversity and species richness.

Protection of ecosystems against human-caused disturbances is important to identify their potential for effective management of biodiversity resources. Considering that, protected areas are in interaction with unprotected areas, it is recommend forest managers to avoid the complete separation of these areas and implemented conservation programs in collaboration with local people to help establish effective management and promote education and proper land utilization and thus help conserve natural resources and biodiversity. The results also suggest that grazing and human activities with low intensity along with controlled frequency of invasive species and judicious utilization of forest resource including selective felling can be considered as an interesting tool if the main objective of forest managers is to protection or even increase plant biodiversity.

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COMPREHENSIVE ASSESSMENT OF KOROSTYSHEV PARK, THE MONUMENT OF LANDSCAPE ART, ZHYTOMYR DISTRICT, UKRAINE

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Abstract

The article is devoted to the analysis of the past experience from the creation of Korostyshev Park, monument of landscape art. The current state of parkland and its structure is examined with historical, taxonomic, landscape and aesthetic evaluation of park area is conducted perspective. The methods and ways of reconstruction of the parkland are elaborated.

Key words: degradation, dendroflora, edificator, geobotanical region, type of park landscape.

Introduction

Ukraine has significant landscape gardening heritage: on its territory there are 88 parks of national importance, with an area of 5,900 hectares (including 68 vintage area 4,675 hectares), and 414 parks of local importance, with an area of 7,100 hectares. Moreover, the natural reserve fund includes 34 arboretum, 24 botanical gardens, 27 regional and landscape parks (Kuznetsov 2003). There are 18 parks, monuments of landscape art of local importance, in Zhytomyr region. Most of them were created before the beginning of the twentieth century on the basis of existing vegetation. We selected six parks for the study that are located in different geobotanical areas, have a larger area and are less researched. In this paper we present the results from evaluation of Korostishev Park, which is located in Zhytomyr geobotanical region of oak and oak-hornbeam forests (Barbarych 1977). The objective was to conduct a comprehensive assessment of the Korostyshev Park, the monument of landscape art of local importance.

Material and Methods

We used materials of creating a park that is stored in the historical museum of Korostyshev town. To achieve the goal of the work, we needed to determine the taxonomic composition of dendroflora. We studied species composition of trees and shrubs by route method. At the same time determining the current health status of the trees using a scale of L. Rysin (Rysin et al. 1988): 0 − healthy trees, 1 − weakened, 2 − very weak, 3 − dries, 4 − fresh deadwood, 5 − old dead wood, 6 − fresh windfall, 7 − old windfall, 8 − fresh windbreak, 9 − old windbreak.

Aesthetic appreciation of the parkland areas were carried out by classification of Kucheryaviy (2008), which includes taxation and emotional scales. Landscapes, analyzed for classification of L. Rubtsov (1956, 1979) are which has allocated 6 types: forest, park, meadow, garden, alpine and regular. He said that landscape is a specially arranged in gardens and parks interconnected systems of vegetation, topography, soil, water and engineering structures that are designed to ensure people certain sanitary conditions, to create the best environment for a particular type of recreation and to provide people the same emotional response. This classification allows us to carry out in different types of landscapes certain measures to optimize them.

In total we conducted researches on the study of the historical features creating the old park including the current state of trees and shrubs, and also carried out a comprehensive assessment of the study area. We answered on these issues in details below.

Results and Discussion

In the XVI century Korostyshev town of Zhytomyr region belonged to Philon Kmita, governor of Smolensk, later hetman of Lithuania. In 1565 Kmita sold Korostyshev for 400 Lithuanian cents to his relative Ivan Olizar.

In the early nineteenth century the estate was inherited by Earl Gustav Olizar. According to his contemporaries he was an extraordinary and well educated man. In 1821, when he was only 23 years old, was elected leader of the nobility in Kiev province, but in 1824 was re-elected for a second term. At the same time became a member of the Masonic Lodge (Kiev "United Slavs"). But for his patriotic beliefs young Earl displeased Emperor Alexander I, and was forced to leave his native land. He decided to go south, first to Odessa, where he met with A. Pushkin, then to the Crimea.

Earl Olizar bought at the foot of the Ayu-Dag a piece of land adjacent to the sea and covered with wild bushes. On the territory of their possessions in 200 tithes (218.5 hectares) Olizar built a manor house with outbuildings, wine cellars and a plantation of olive trees. The earl became seriously interested in landscape art in the Crimea, and translated from the French Delile poem "Gardens", which in turn has had a huge impact on the development of landscape architecture at the time.

In 1836 Gustav Olizar returned to Korostyshev and for more than 20 years he lived there with his wife. The Earl's Crimean experience was influential in his decision to fix his father's estate. According to his plans, the park must combine elements of the past and present, to remind the public of people, events, distant lands and Masonic interests. On the upper terrace, where the castle once stood, was constructed in the regular style parterre (Figure 1), which was placed in the center of the pool with a decorative arch of granite with Masonic symbols. Lawn bosquets correct forms were edged with a border of annuals undersized flowers. In the corners there were planted pyramidal shaped arborvitae, and along the borders with green spherical boxwoods. In the depths of the manor there was built a small two-storey house. The platform before it was planted with Berlin Poplars.

Predominant among the trees were oak, pine, spruce and maple. He also planted trees, imported from Italy, France,

Germany and the Crimea (Yerkulova 2002, 2003; Ershov 1986; Rodichkin I. and Rodichkin O. 1999).

The current state of the park phytodiversity is poor, most trees which were planted by Earl Olizar, dropped out of the plantation (Table 1).

The dendroflora of Korostishev Park includes a total of 29 species, of which only 14 are introduced. This figure is worth considering in development of the reconstruction project.

Fig. 1. Castle of Gustav Olizar (photos of the early 20th century).

For the convenience of analysis, the dominant woody vegetation inventory indices are considered within the sections that have been allocated in accordance with the requirements of landscape inventory. For each section the main inventory indices has been identified (Table 2).

The former dominant *Quercus robur* is found only in section 6 and takes less

Table 1. Taxonomic composition of the Korostyshev Park, the monument of landscape art.

Species	Introduced species*	Species	Introduced species*
Acer negundo L.	+	*Picea pungens* Engelm.	+
Acer platanoides L.	-	*Populus alba* L.	-
Acer pseudoplatanus L.	-	*Populus tremula* L.	-
Acer tataricum L.	+	*Pyrus communis* L.	-
Acer saccharum Marshal	-	*Quercus robur* L.	-
Aesculus hippocastanum L.	+	*Robinia pseudoacacia* L.	+
Betula pendula Roth.	-	*Salix alba* L.	-
Carpinus betulus L.	-	*Salix fragilis* L.	+
Fraxinus excelsior L.	-	*Sambucus nigra* L.	+
Fraxinus pennsylvanica Marsh.	+	*Sorbus aucuparia* L.	-
Juglans regia L.	+	*Syringa vulgaris* L.	+
Malus domestica Borkh.	-	*Thuja occidentalis* L.	+
Morus alba Borkh.	+	*Tilia cordata* L.	-
Parthenocissus quinquefolia Planch.	+	*Ulmus glabra* H.	-
Picea abies L.	+		

*Note: "+" – an introduced species, "-" – aboriginal species.

than 10 % of the territory. In the first section there is no dominant species, the reason for this is manmade plantations and their functions. This section is a memorial area, which is dedicated to those killed in the world wars and soldiers-internationalists. In the center was created alley with *Picea pungens* along which were planted flowers. Near was placed a small area for events in honor of the heroes of the war.

Table 2. Feature plantations Korostyshev Park, monument of landscape art.

Section	Composition plantings**	Stand density	Crown cover	Area, ha	Predominant species	Height, m	Diameter, cm	Sanitary condition	Class aesthetic value
1	3Pp2Fe2Tc2Ac1Ah+Ug	0,5	0 ,4	2,11	*Picea pungens*	20	22	2	II
					Aesculus hippocastanum	24	52	2	
					Ulmus glabra	26	50	2	
					Tilia cordata	24	30	1	
					Betula pendula	22	24	1	
					Acer saccharum	26	54	4	
2	4Rp2Fe2Ap1Ac1Ug+Pt,Pa	0,4	0,3	1,92	*Robinia pseudoacacia*	26	38	1	II
					Fraxinus excelsior	28	44	1	
					Acer platanoides	26	40	1	
					Acer saccharum	25	34	2	
					Ulmus glabra	28	62	2	
					Populus tremula	30	88	2	
					Populus alba	29	84	3	
3	3Fe2Pt2Ug1Tc1Ac1Ap	0,6	0,5	2,11	*Fraxinus excelsior*	30	68	2	III
					Populus tremula	29	72	2	
					Ulmus glabra	28	80	1	
					Tilia cordata	26	36	1	
					Acer saccharum	30	98	2	
					Acer platanoides	27	38	1	
4	3Cb3Fe2Rp1Ap1Pt	0,7	0,8	1,9	*Carpinus betulus*	26	40	1	III
					Fraxinus excelsior	29	50	2	
					Robinia pseudoacacia	27	46	2	
					Acer platanoides	24	34	1	
					Populus tremula	29	62	2	
5	4Ap2Tc2Ug2Pt	0,3	0,4	1,6	*Acer platanoides*	26	34	0	II
					Tilia cordata	28	88	1	
					Ulmus glabra	26	36	1	
					Populus tremula	29	98	2	
6	3Sa2Ug2At2Ap1Tc+Qr	0,8	0,7	3,2	*Salix alba*	28	98	2	III
					Ulmus glabra	30	96	2	
					Acer tataricum	24	36	1	
					Acer platanoides	24	38	1	
					Tilia cordata	26	68	2	
					Quercus robur	29	100	2	

**Note: Pp – *Picea pungens*, Qr – *Quercus robur*, Fe – *Fraxinus excelsior*, Ap – *Acer platanoides*, Ac – *Acer saccharum*, Ug – *Ulmus glabra*, At – *Acer tataricum*, Tc – *Tilia cordata*, Rp – *Robinia pseudoacacia*, Sa – *Salix alba*, Pt – *Populus tremula*, Cb – *Carpinus betulus*, Pa – *Populus alba.*

For the second section the dominant introduced species is *Robinia pseudoacacia*. Despite the fact that both *Fraxinus excelsior* and *Acer platanoides* give plentiful seeding, in the territory they they occupy only 20 % of the territory. This suggests that the conditions for the germination of undergrowth *Robinia pseudoacacia* are ideal, and its degree of adaptation as an introduced species is still relatively high.

In other sections are the same situations. *Quercus robur* was ousted from phytocenosis by *Fraxinus excelsior*, *Acer platanoides*, *Carpinus betulus*, *Tilia cordata* etc. One of the reasons for this is that after revolution 1917 care of parkland was not performed. *Quercus robur* was being cut as a precious wood, and new cultures of this species were not propagated.

Most of the mature and over mature trees in the park are greatly weakened or dead, exposed to the influence of pests and diseases. *Tilia cordata*, *Ulmus glabra* and *Carpinus betulus* are also weakened. In 5 section *Acer platanoides* is completely healthy.

About aesthetic evaluation of phytocenoses park there is next situation. First class aesthetic value is missing, the second classes are 1st, 2nd and 4th sections, and the third classes are 3rd, 5th and 6th sections. As mentioned above, the first section is a memorial area, so plant care is performed regularly. In 4th section reconstructive work took place. As a result snags and windfall trees were removed and the network of road and paths were repaired (Figure 2).

There are cluttering scrubland and on the grassy tiers the rest of the park. Low patency territory, depth perspective, coloring/illumination at a low level, and the underbrush are sparse. This area requires reconstruction and restoration work at the first place.

Fig. 2. Fourth section after reconstruction.

Table 3. Distribution of the types of landscapes at Korostyshev Park.

Type of landscape	Area	
	ha	%
Forest	4.28	33.2
Park	7.66	59.4
Meadow	0.51	4.0
Garden	0.00	0.0
Regular	0.37	2.8
Alpine	0.08	0.6
All	12.90	100.0

We conducted a landscape analysis of Korostyshev Park territory (Table 3).

The forest type of landscape is about 1/3 of the territory, mostly along the river Teterev. The basis of the tree stand is formed by *Acer platanoides*, *Tilia cordata*, *Ulmus glabra*, *Salix alba* and

Fig. 3. Park type of landscape in Korostyshev Park.

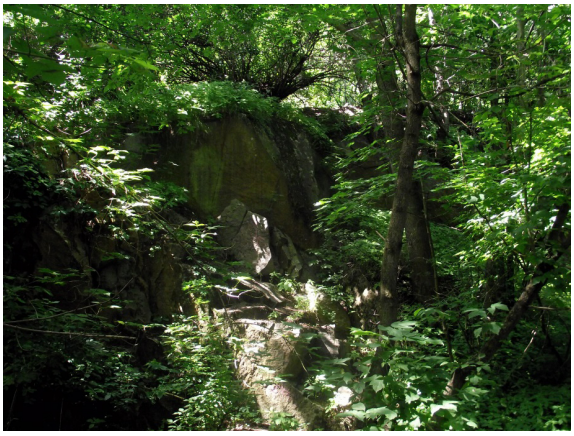

Fig. 4. Alpine type of landscape.

Populus tremula. The park type of landscape (Figure 3) is about 60 % of the study area (1st, 2nd, 3rd and 5th sections). This figure is high for historic parks in Ukraine.

Regular type of landscape that presents alleys of *Picea pungens* and *Acer saccharum*, meadow and alpine types occupy less than 1 % of the territory. Given that Korostyshev is on the Ukrainian crystalline shield it is particularly interesting that there are the sections of outcrop granite (Figure 4.)

Conclusions

After conducting of our research, we can draw the following conclusions:

1. According to the archival materials about Korostyshev Park, monument of landscape was created in the late sixteenth century. In the early nineteenth century it was renovated by Earl Gustav Olizar in regular and landscape styles.

2. During management graph Olizar park was in the corresponding state. After 1917 due to lack of care, the parkland occurred taxonomy degradation. Most species, especially exotic ones, have died out of plantations. Former dominants *Quercus robur* was superseded by *Fraxinus excelsior*, *Acer platanoides*, *Tilia cordata* and *Carpinus betulus*.

3. At this time, the composition of dendroflora is represented by 29 species of which 26 trees, 2 shrubs and 1 tree climber. Only 14 species have been introduced species.

4. Most of the park mature trees are strongly weakened or dead and stands exposed to the influence of pests and diseases. Moreover, even native species of trees are in a weakened state.

5. Territory, which has second class aesthetic value, occupy 3.90 hectares (30 %). It is cluttering both scrubland and on the grassy tiers the rest of the park. Low patency territory, depth perspective, coloring and illumination at a low level, and the underbrush is sparse.

6. Types of landscapes are as follows: forest – 4.28 ha (33.2 %), park – 7.66 ha (59.4 %), meadow – 0.51 ha (4.0 %), regular and its elements – 0.37 ha (2.8 %), alpine – 0.08 ha (0.6 %).

7. Reconstruction is primarily needed in 3rd, 5th and 6th sections. Necessary to carry out the cutting of dead, windfall trees and impassable. Also need to eliminate clutter, repair and optimize road and network of paths. Cuttings of *Quercus robur* were planted on-site restore its edificatory role.

8. Necessary to create a composition of native species of trees and shrubs that are more stable under these conditions.

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